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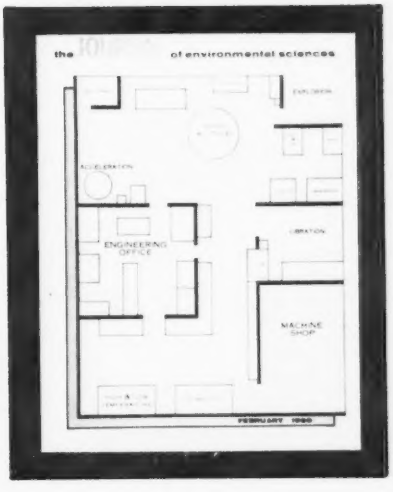

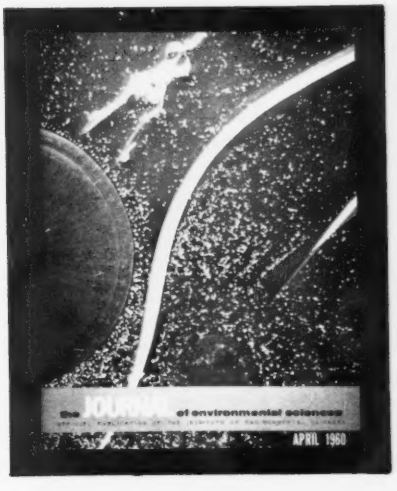

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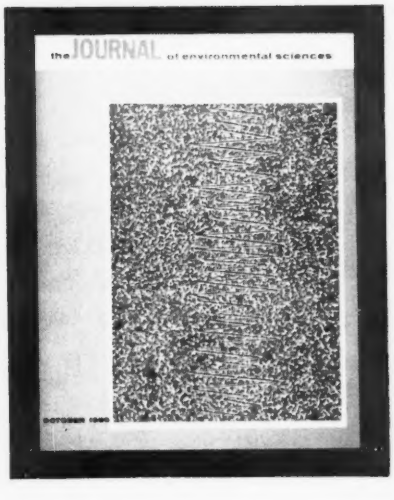

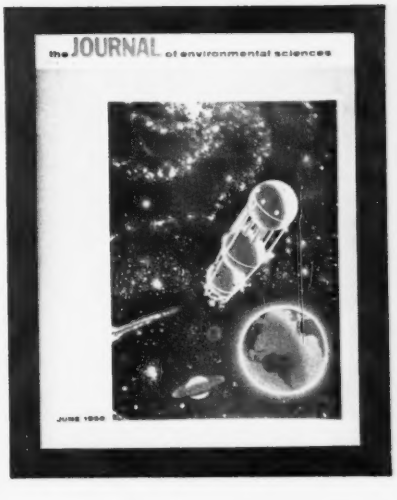

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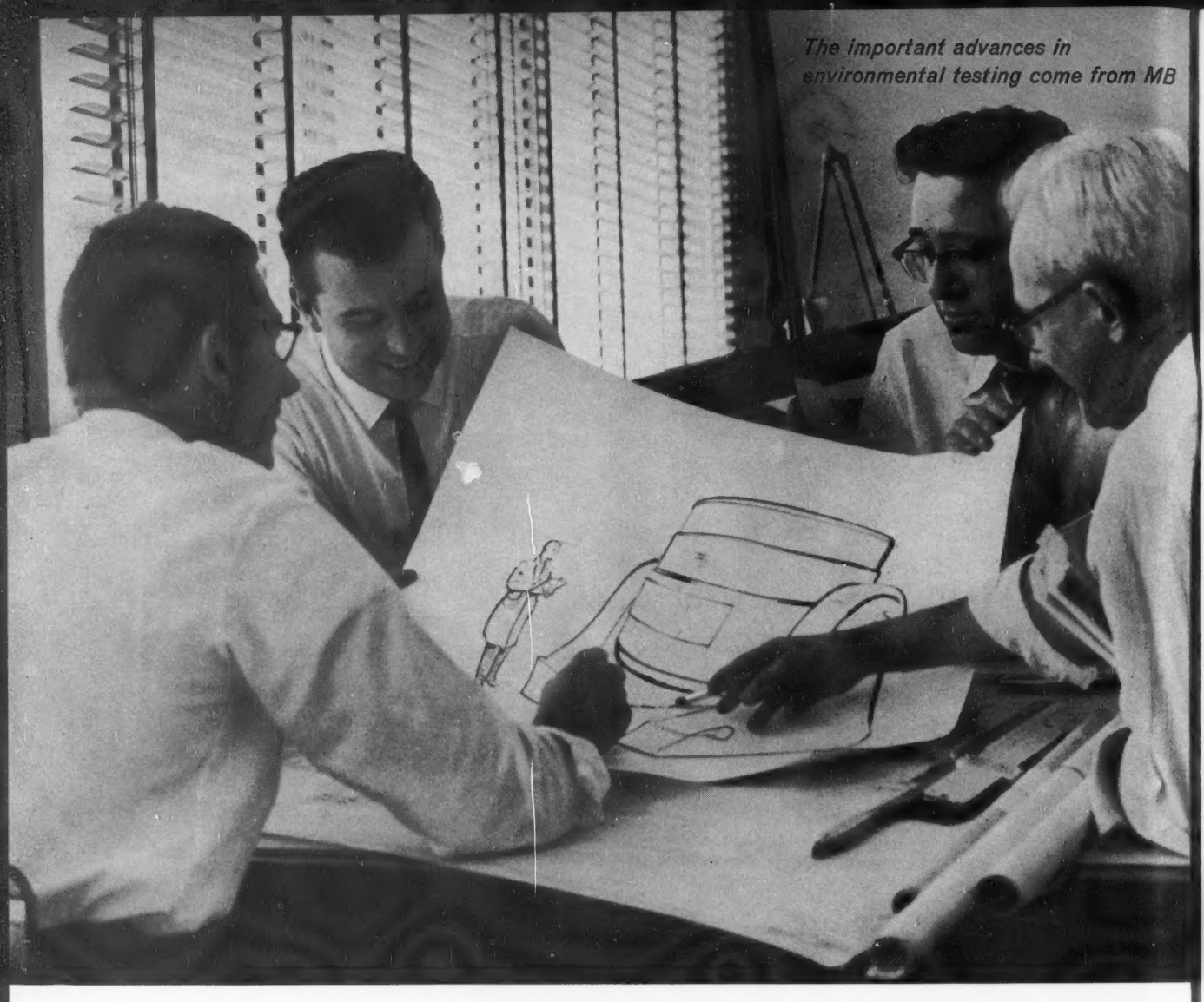

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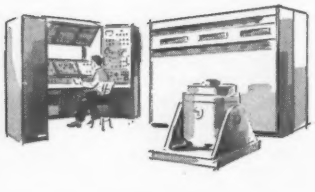

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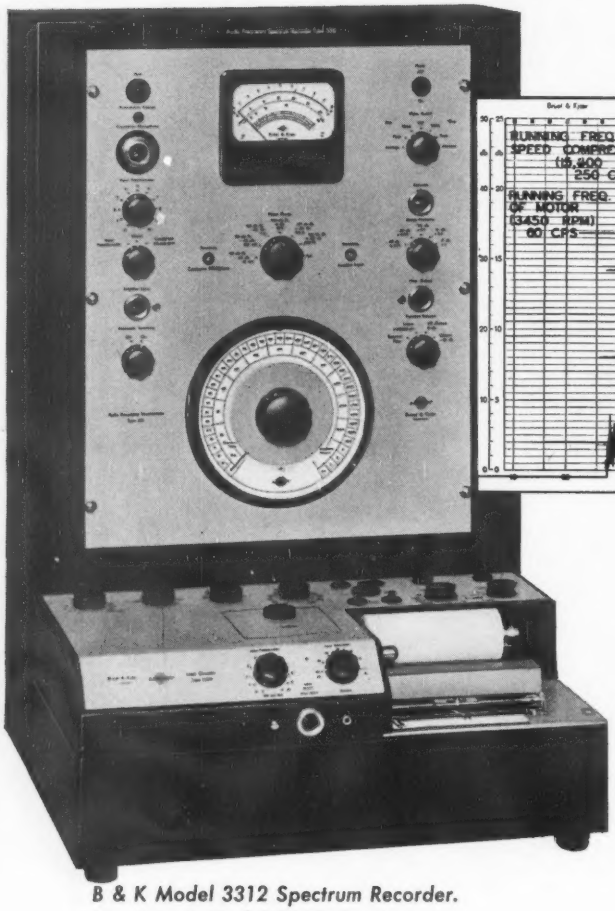

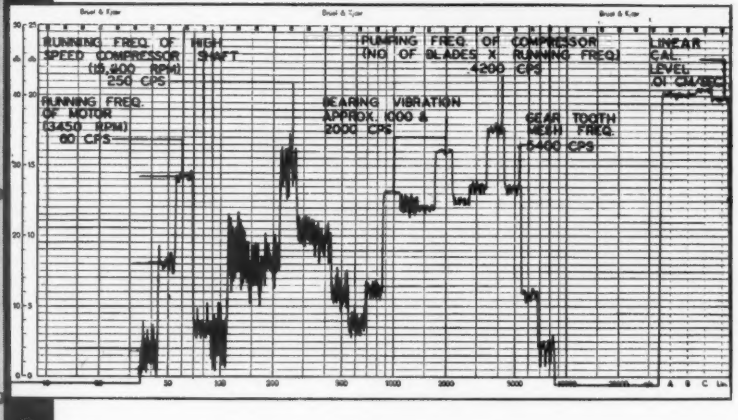
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Reliability Planning in Space Systems

BY VERNON L. GROSE

HEAD, RELIABILITY STAFF GUIDANCE SYSTEMS LABORATORY
ELECTRONIC EQUIPMENT DIVISION, LITTON SYSTEMS, INC.,
SUBSIDIARY OF LITTON INDUSTRIES

Concluded from the October Issue

Whenever a prediction is made, it is assumed that a measurement to validate the prediction will follow. This aspect of measurement opens a new chapter of problems, not the least of which is realistic simulation.

And not only is the predict-measure procedure time-consuming and difficult, it is compounded by those customers who desire *several* measurement tests followed by a refined estimate, with each successive test becoming a more difficult (and probably less accurate) simulation.

These are the more obvious areas where reliability prediction has been unable to contribute to the achievement of reliability. However, while these factors are so well known by those who are responsible for reliability achievement as to be considered platitudinous, there are additional primordial, basic aspects to current predictive techniques which are not only deterrents to prediction efficacy but also unrecognized by a majority of persons responsible for reliability prediction. These basic components have been denominated as the subtle aspects of reliability prediction inefficacy.

THE SUBTLE ASPECTS OF INEFFICACY

The statistical techniques used for measuring reliability today usually involve a failure probability distribution that is exponential, and it is always a tacit assumption that this distribution is accurate. Actually, very few applications of this distribution are accurate, and what is worse, seldom does anyone know how inaccurate they are.[1]

Even though the exponential function is, for purposes of practicality, the only distribution utilized today for predictive work in reliability, the probability density function for occurrence of failures of a device as a function of time (sometimes called mortality function) may take a completely different shape depending on the type of device tested, the arrangement of the experiment, the environmental conditions, the definition of a failure, and even the interpretation of the experimental data. In fact, six basic mortality functions are known to apply to various complex equipments, and the pure exponential or chance mortality function (constant force of mortality) is included only in the gamma function and the third asymptotic mortality function as a special case (where $\sigma = 1$).[7]

To further complicate the possibility of assuming accurately an underlying failure probability distribution for complex equipment, it is known that the mortality function of a device is normally a combination of two or more basic mortality functions or two or more functions of one basic mortality function having different parameters. To combine several mortality functions, their forces of mortality have to be added.[7] This results in a distribution which is not only absolutely unique to one equipment type in one particular application but also sufficiently complex as to not permit mathematical definition. In other words, the "hypotheticalness" of a statistical approach to reliability prediction more often relegates the problem to the same significance as those which propose to solve the world's ills by first assuming that every man is sinless.

It is undoubtedly true that the exponential distribution of failure would long ago have been abandoned by reliability personnel as an efficacious assumption if (1) statisticians had known more about engineering problems and (2) engineers had realized the superficial and unrealistic aspects of the assumption. While it is not propounded here that there could not, by accident, conceivably be some complex equipment which might fail in a pattern which closely resembled the exponential case, it has not been conclusively proven by any published data available to this author. An examination, then, of the exponential distribution and its associated by-products in reliability prediction is imperative to reveal the subtlety of its inefficacy.

Appendix A contains some of the inherent assumptions that must be valid if MTBF (mean time between failures) is to be utilized as a reliability measure of merit. Since MTBF and the exponential assumption may be considered, for purposes of discussion, as synonymous in reliability usage, it might be noted that *none* of these assumptions is valid for complex equipment being delivered to the military establishment today. If examination is made of each assumption, it can be seen exactly why they are in error:

Assumption 1 -- As an absurd but valid example, it would be possible to prove that a simple 24-hour alarm clock has millions of hours MTBF, if thousands of clocks were wound and measured for only the first eight hours after winding. If none of the clocks failed in the first eight hours, eight failure-free hours would be tabulated for each one and, since MTBF is computed by simply adding up the hours of successful operation and dividing them by the failures which occurred during the same period, the MTBF would be infinitely large in a short time, and yet the clock was designed to

operate only 24 hours without failure (i.e., without being rewound).

Assumption 2 -- In practice, a majority of failures occurring in complex equipments are due to wearout. There are, of course, a certain percentage of design or human causes, and even the wearout failures could be described as design errors. Nonetheless, each failure should be treated as having a cause. Reliability practitioners are almost universally guilty of treating "random" as a cause or else implying that these failures have no cause when, in a majority of cases, they are wearout failures.

Assumption 3 -- The science of environmental simulation makes no claim of being able to impose simultaneously a complete environmental envelope of stresses which even the simpler weapon systems will experience in service.

Assumption 4 -- There is not an engineer who would accept this assumption because, if nothing else, his intuitive judgment would tell him that everything begins to wear out with its initial operation. It is true that the wearout rates could be very small, but some items in a complex equipment would show rates that were very high. Data gathered in conclusive quantities by such organizations as ARINC Research Corporation reveal that wearout of component parts of complex equipment begins immediately with initiation of service.

Assumption 5 -- Because of this assumption, MTBF, either as a predictive or measurement device, is without significance except for logistic problems. Without knowledge as to what failed, what caused it to fail, and what can be done to prevent it from recurring, a simple count of hours of successful operation divided by the number of failures has no meaning to the designer. Consider the case where one system might have 200 hours MTBF but fails every time in explosive disintegration, and compare it with another which has only 50 hours MTBF because of temporary drift problems which do not abort the mission. Which would you select?

Assumption 6 -- It is very seldom that a failure occurs which does not affect portions of the equipment aside from the failed part. Furthermore, since varied amounts of redundancy do exist in complex systems, this assumption is invalid.

In addition to the invalidity of the basic MTBF assumptions, there are other aspects of practical application of MTBF, both as a predictive and measurement device, which are worthy of consideration. Foremost among these is the practice of predicting system performance from bits of data on component performance. Considerable statistical study of this approach has been made and is still being pursued. Contrary to the prevalent trend by contractors of military equipment to take a parts list of a system, assign failure rates to each component part, add and multiply at will, and arrive at a system reliability index, it has been shown that the process must be much less superficial to possess merit. For example, prediction of system performance involves intuitive choice between three essential dependent relationships of system performance to component performance as well as several hypothetical interdependent relationships.[8]

Since the component part failure rate data are so general, there is no method for determining the effects of such vital facets as circuit design, packaging techniques, system environmental vulnerability, and system integration factors on the failure rates. If the method for predicting MTBF were straightforward and unambiguous enough so that every predictor was consistent in the value estimated, it would be possible to use these values for at least comparative purposes while perhaps even openly recognizing that they had no *absolute* significance. But even this possibility is over-ruled because the hocus-pocus utilized by each individual estimator to fill in for missing data or unknown effects of new environmental and/or service parameters on existing data places the method in the artistic -- not scientific -- realm. A group of reliability estimators who are given the same set of drawings today for a complex system and instructed to estimate the MTBF will produce as many different estimates as there are estimators. This inefficacy of prediction may well have precipitated the decision of one of the military customers to speak of ranges rather than discrete mumerical reliability indices.[6]

There are those who would suggest that, in the past near-decade since prediction became popular, complexity of our equipment on the average has increased at a rate which overshadows the gains in reliability which should be credited to prediction techniques. There is danger, however, in confusing facts with excuses. Complexity increase is a fact, but it certainly should not be offered as an excuse for not achieving reliability or, for that matter, not reaching any goal that we set for ourselves; e.g., hitting the moon.

PREDICTION SYNOPSIS

To predict or not to predict -- this must be resolved. Should reliability continue to be pursued "by the numbers?"

On the strength of achievement versus inefficacy to date, it would seem that the evidence is heavily in favor of diverting the funds, time, and effort normally spent on prediction and measurement into more extensive test programs which are the only sources of relevant factual data to guide the designer. It does not appear even logical to become involved in predicting and measuring a parameter (reliability) which, in the final analysis, is not appreciably influenced by the predict-measure effort and, further, will be accepted virtually without regard for its value by the customer.

In practical terms, the military establishment cannot afford to develop and produce parallel weapon systems for every tactical need. Therefore, the defense arsenal is ultimately filled with singular weapon systems (i.e., only one system for one tactical requirement) which have been sustained through development to pro-

duction for many other reasons than scientific excellence; e.g., reliability, economic, political, geographic, timely procurement, et cetera. In those cases where scientific excellence is not the prime criterion, the predict-measure effort (even if accurate!) is inconsequential regardless of the actual reliability of those weapon systems. Knowing full well, then, that a sizable portion of our defense posture may be procured for reasons other than scientific, does it not appear cogent to get busy and *achieve* reliability through knowledge (testing) of what fails, thereby being able to prevent failure, than to spend precious time, effort, and money on conjecture?

IMPLICATIONS OF THE SPACE AGE

The possibility of no longer being earth-bound has presented man with a new frame of reference. While the possibility is somewhat more than feasible, it is still fraught with limitations of which man is, at the moment, both creator and victim. In particular, the reliability of vehicles and devices to be used in inhabiting and traversing outer space present man with diverse considerations. At what stage of development of space vehicles should he risk his life by taking a ride? How will he know when this stage of development has been reached? What portion of the stresses to be encountered in space will be able to be accurately simulated before manned flight? How great a risk will he be taking at the time he does decide to leave Earth behind? These are but a few questions that will be asked and which bear on reliability in the Space Age. Obviously, concepts must be optimized and reliability planned methodically if success is to result.

SCIENTIFIC CONSIDERATIONS

There will be presented to the designer of space vehicles some specifications which will appear restrictive in one case and somewhat relaxed in others. For example, mission profiles will more than likely be much simpler for spacecraft than for manned aircraft. But, at the same time, even though there will be fewer stages in the mission, less will be known about each individual stage. Many of the environmental stresses which will be encountered in space have yet to be simulated effectively on earth, so equipment operability will remain questionable until either a considerable number of instrumented unmanned flights have been made or laboratory simulation becomes possible.

The life sciences, presumedly through the field of Human Engineering, will extend a much greater influence over the hardware designer. This will be necessary because, for perhaps the first time, man's creation may be smarter than its creator after getting into space, and man may well become a detriment to have aboard, due to poor judgment.

How will reliability's role change, if at all, in equipment design and production? Most decidedly, it will change from a statistical function to one of laboratory validation of design. This is true not only because there will be less samples for statistical evaluation, but there will be no firings with human occupants just to meet a schedule or because someone has computed a certain MTBF for the space vehicle. There will have to be *convincing* data before man's life will be risked.

Even if the Prediction Synopsis had indicated that prediction had contributed to the achievement of reliability in manned aircraft and guided missiles, such new considerations as years of unattended operation in orbit and the need to know with great confidence, prior to launch, whether success is imminent would make the predictive approach prohibitive. Figure 1 is an estimate of the state of the prediction art and its future extrapolation.

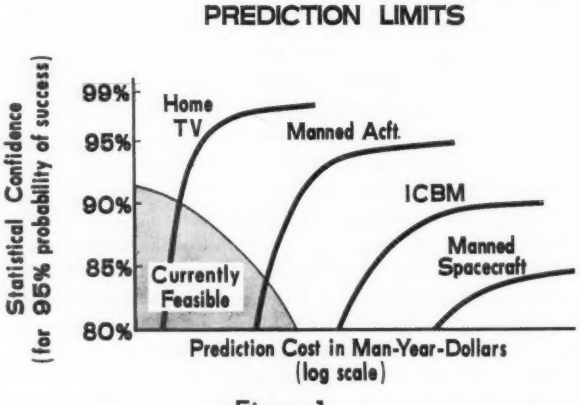


Figure 1

It can be seen that with large production of a simple electronic device like home television sets, 95 percent reliability could feasibly be assured with confidence approaching 99 percent, although our present knowledge limits the confidence in the 95 percent probability of success to approximately 90 percent. Nevertheless, even this much confidence is verified by the fact that manufacturers issue warranties for television sets. However, as we look at manned aircraft, 95 percent reliability of operation can, at best, be predicted only with 80 to 85 percent confidence. It is assumed that, given enough money, time and effort, this confidence level could be raised to approach 95 percent. Proceeding to the ICBM, it is evident that 95 percent reliability with any confidence statement at all is, as yet, quite remote in terms of time and money. At best, it is estimated that the confidence in 95 percent reliability for the ICBM would never reach 90 percent. Manned spacecraft simply show the impracticality of utilizing prediction as an achievement tool for reliability.

A few months ago, the Air Force verified the position that a new approach to reliability is mandatory for space systems by the following statement: "With these new requirements (of systems having to operate continuously for periods of years), old methods of hypothesis

testing will no longer be adequate. The mean-time-before-failure concept used extensively in determining reliability today will be meaningless for future systems."[3] What is needed for space systems? The first order issued for reliability regeneration should be a call to abandon the word "probability" or, if it is to be retained, it should be permitted to reach 100 percent. As long as reliability is thought of as something less than unity, everyone will be satisfied with some degree of failure. Contrary to the statistician's hypotheses, devices can be 100 percent reliable. Without any semantic wrestling, it is proposed that the method of achieving 100 percent reliability is by overdesign.

Nature's lengthy experience with the reliability problem has led her to adopt some very interesting design principles. Brief study indicates that these principles are followed in all organisms that are living today. Perhaps the most important principle followed by Nature is that of "overdesign." The long periods of testing have eliminated all beings which possessed too little reserve strength to survive severe stresses. Consider the frequency response capability of the nervous system, for instance. Some nerve fibres are capable of responding 2000 times per second while the normal stimulation rate in them is from 10 to 100 pulses per second, and the rate very rarely goes as high as 500 pulses per second. An audio amplifier designed in accordance with Nature's example would have a frequency response well above 80,000 cycles per second.[2]

Overdesign should not be considered as relegated to multiplying estimated required maxima by three or four. There are actually many ways of achieving overdesign; for example, redundancy and the mismatching of equipment sensitivities with service stresses. In all cases, it is the allowing for a factor of safety which has been better described as an ignorance factor.

Overdesign has been branded by many engineers as not being sophisticated. However, it might be well if design sophistication were to be re-evaluated. It would appear that for a design to be truly sophisticated, it must first be capable of performing reliably. If, after accomplishing reliable performance, it is possible to trim weight, volume, and cost, these comprise *additional* sophistication. To illustrate this premise candidly, before we brand our competitors in the Space Race as lacking design sophistication because they throw bathtubs at the moon while we are supposedly able to accomplish moon impact with a basketball, the fact remains that they hit the moon first!

ECONOMIC AND POLITICAL CONSIDERATIONS

Science and engineering have stepped to the forefront of public attention in the past few years to the extent that it becomes evident they must concern themselves not only with scientific facts but also with how these facts influence such fields as economics and politics. It is not proposed that the decision for the United States to compete or withdraw from the Space Race (a decision which has not yet apparently been made) should be resolved in this paper. Nevertheless, each scientist and engineer should be cognizant that, if an affirmative decision is made to race in space, predictions of success followed by failures which are capable of being suppressed by devious means will no longer suffice. No longer will it be possible to hide failures. We will either be in orbit or we will not, and the whole world beholds and objectively evaluates our success.

In the light of this, the question is asked, "Can engineers and scientists continue to be technical specialists devoid of economic or political compulsion ?" There is a definite need for a moral code for engineering science because it may be possible that decisions upon which an entire way of life could depend will lie within the domain of the reliability engineer who insists on facts rather than conjecture.

THE RELIABILITY ANALYSIS FOR PRELIMINARY DESIGNS

While this paper thus far has been devoted to exposing deficiencies in the present techniques for achieving reliability, and has compounded this expose with a declaration that the problems of achieving reliability in outer space are several orders of magnitude greater than current problems being treated inefficaciously, there is set forth here a solution. This solution is not predicated on resolving the impasse between the reliability statistician and the designer via compromise. It is a fresh start established and impelled by the question, "What would *I* want done to assure a safe trip into outer space if *my* life depended on it?" If a certain MTBF would not be adequate assurance (and it would not), then what would be required? The method as proposed here is felt to be what a logical thinker would endorse.

ITS CONSTITUTION

The catalyst of this method is a prepared form called *Reliability Analysis for Preliminary Designs* and shown in Figure 2. Contrary to the current popular trend, there are no magic formulae utilized which only the originator understands but which are applied by all practitioners unquestioningly. Neither is there a dazzling display of deceptive decimals. It *is* a method that designers understand and enthusiastically endorse. It is so constituted that the designer, normally pursuing the ultimate threshold of performance in his design, is permitted the luxury of a realistic view of his design -- realism which consists of cognizance of failure possibility. With this method, the designer quits fighting reliability personnel and joins them, becoming the first and most prolific source of reliability information through the entries which he makes in the form.

For those who would object to the predominantly qualitative nature of the form, it might be well to consider how this aspect is handled in the field of systems analysis. It has become necessary in that field to differentiate between at least three kinds of conclusions -- what might be called intuitive judgment, the considered opinion, and the technical or scientific "fact." The latter will not be considered relevant to discussion of the reliability method proposed herein, but the first two types of conclusions are significant.

Intuitive judgment is defined as a conclusion which is essentially based on a person's background,

education, and experience. This is the basis for the majority of everyone's decisions. The important facet for this discussion is that, while it may be an informed conclusion, the machinery by which it has been arrived at is not explicitly shown, and it becomes as good or bad as the person who makes it.

Considered opinion, on the other hand, differs from intuitive judgment in that the logic behind the judgment is made explicit, and this usually means that it is quantitative. While the value of the conclusion still depends on the person who makes it, insofar as the logical machinery is clearly shown and not hidden by a mass of charts, calculation, and technical verbiage, the evaluator has some chance of making his own private and considered opinion from the information presented.[5]

It would follow, then, that the entries in this form are considered opinions rather than merely intuitive judgments, and the form does possess a certain quantitative value even though it contains words rather than numbers.

By noting the entries in Figure 2, it can be seen that the only numbers are for cataloguing purposes (pages and failures) and the date. Before this method is banned by the reliability experts for retrogressing from quantitative indices back to qualitative verbiage, it should also be noted that failures listed on this form are ultimately ranked quantitatively. The quantification is purposely accomplished, however, by alphabetization rather than numeration, to prevent any erroneous extrapolation by the overambitious.

ITS APPLICATION

As mentioned earlier, this form is completed by the designer -- not the reliability expert. The only exception is the column, "Probability of Occurrence at Present State-of-the-Art," which is an entry made by the reliability consultant after a concensus has been reached with the designer, several design specialists of the same discipline who are uncommitted to the particular design, and the reliability consultant. Since an earlier allusion to the term "probability" indicated that its abandonment or at least revision of current definition was mandatory, it is defined, unmathememathically, as a general possibility of failure occurrence.

It is important that reliability personnel constantly remember that their function is one which is secondary to the designer. The designer is "king", and whatever contact is made between designers and reliability experts should provide the designer with a minimum of distraction and a maximum of helpful information. Therefore, this form requires that the reliability engineer do some tasks which are not always glamorous, but the designer is impeded minimally.

RELIABILITY ANALYSIS FOR PRELIMINARY DESIGNS

NO.	ITEM	CONCEIVABLE FAILURE	MECHANISM OR INDUCER OF FAILURE	CONSEQUENCE OF FAILURE ON OVERALL MISSION	FEASIBLE TO OBVIATE FAILURE?	DETERRENTS TO FAILURE OBVIATION	PROBABILITY OF OCCURRENCE AT PRESENT STATE-OF-THE-ART	REMARKS
1.	Primary Mirror	Reduced reflection from externally-mounted mirror	Etching by impingement of micro-meteorites in orbit	D_c	Yes	Weight of adequate shielding & reduction of search cone	A_p	(1) The degree to which shielding is effective is a function of satellite altitude & tracker line-of-sight angle. (2) Shielding has not yet been conclusively proven as being adequate.
2.	INXXX Diode	Intermittent open	High-frequency (above 1 kc) mechanical vibration of more than ± 13 g	C_c	No	(1) State-of-the-Art (2) Weight and volume of adequate isolation devices (3) Cost of new diode development	C_p	Would recommend circuit redesign to use a rugged diode which is already available.

Figure 2

Before the designer makes the first entry in the form, he should be furnished a simple primer on the meaning and implication of reliability. If he understands the simplicity (and it should be kept as simple as it really is) of the purpose behind reliability, his approach will be far better than if he entertains the prevalent thought of reliability personnel as "overhead underfoot."

The entries in the form follow these rules:

1. *Conceivable Failure* -- *All* conceivable failures are listed, including both degenerative and catastrophic types. Even failures thought to be most remote in possibility are listed. The designer is instructed not to list what he thinks will happen but rather to list everything which *could* possibly fail. A complete environmental envelope and mission profile are furnished, and their effects on various types of materials and components are delineated, so that the designer's imagination is stimulated to assess the effects of each stress as to its failure-inducing capability.

2. *Mechanism or Inducer of Failure* -- *Something* is the cause of any specific failure, and this cause should be traced to its root -- even if it consists of molecular impurity unbalance. Only when the true cause is known can reliability be achieved.

3. *Consequence of failure on Overall Mission* -- Not all failures, particularly degenerative phenomena, will result in a total reduction of system capability. Table I of Appendix B contains five possible consequential categories. The designer is requested to use this code although it may not completely describe each failure consequence exactly. This entry becomes part of the ranking code in later tabulation.

4. *Feasible to Obviate Failure?* -- This column contains either a "yes" or "no" as to whether it is technologically possible to eliminate the mechanism or inducer of failure at the present time. If a "yes" is entered but the failure has not been obviated, the "yes" will be considered as "no" in the next column.

5. *Deterrents to Failure Obviation* -- As mentioned above, there will be an entry in this column in any case except when "yes" was entered in the above column *and* the failure possibility has been obviated. Entries here might include such items as excessive weight, cost, development time, and reduction in performance, any of which would in the designer's estimation defeat the design function if incorporated to eliminate failure.

6. *Probability of Occurrence at Present State-of-the-Art* -- As mentioned earlier, the entries in this column will be the result of a discussion between the designer, a reliability consultant, and several design specialists of the same discipline who are uncommitted to the particular design. Table II of Appendix B contains five different probabilities, one of which should be entered.

After the form is completed, the reliability personnel place the failures in rank order as determined in Appendix C. This order, based on a combination effect of consequence and probability of occurrence, ultimately permits a "totem pole" of failures to emerge, with those most needy of technical management's attention on top. Management may then apply dollars-manpower-time at the top and be constantly aware of the consequences of reducing or increasing the funds spent for reliability.

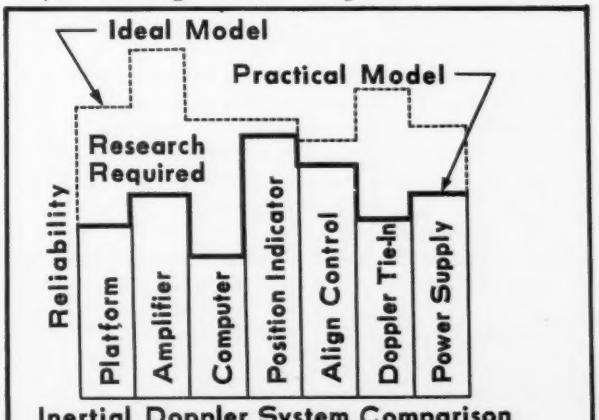
ITS EFFICACY

The statement that "reliability must begin in the design stage," while trite, carries with it an implication often overlooked -- namely, that the *designer* holds the option on how much reliability will ultimately exist in the design. He is capable, if it is his nature, of paying "lip service" to reliability advisors (even if they are present during conceptual studies) while continuing to substitute his intuition for experts' advice. Therefore, he must be *sold* on any principles of reliable design that he may not already utilize. To sell him requires LOGIC and TECHNICAL ABILITY, and (1) this is what has been traditionally lacking in reliability efforts; e.g., edicts from management or anywhere else will not force the designer in the way which is necessary, and (2) this is what this method as proposed herein possesses. To emphasize this latter point, a number of designers have remarked after completing this form that this type of study is one which they would have liked to have done, but time had not permitted it.

While discussing the time required to complete this type of study, it should be clarified that the shortage of time to conduct this type of study in the past has not resulted from the designer refusing to take the time, but management pressure has crowded this aspect out of good design practice. Among the opinions voiced (mainly by personnel with long acquaintance with standard reliability practices) prior to the institution of this method were those negative ones which said that there would be no designer interest, excessive political interference, and lack of designer time to make the entries. None of these proved to be valid.

ITS FUTURE GROWTH

This method is being expanded to permit system-to-system ranking as shown in Figure 3.



Inertial Doppler System Comparison
Figure 3

Through this approach, it will be possible to reveal those areas which require the most research to meet an over-all ideal goal of reliability. Since there will be an additional factor of funding to consider, the aspects of quantitative ranking will not be as simple as in the analysis form for any one system.

CONCLUSIONS

The following advantages result from the employment of this method:

(1) It allows optimization of systems early enough to effectively yield reliability.
(2) It provides a non-political approach to the expenditure of funds and effort.
(3) It permits the ranking of research effort and testing emphasis at an early enough date to secure life test data.
(4) It points up impossible approaches early.
(5) It has long-range educational value to design groups and those responsible for advance concepts.
(6) It gives the individual engineer a forced look at his equipment.
(7) It provides a legal channel to pass the word that a particular design or concept is poor.

APPENDIX B

CODES -- RELIABILITY ANALYSIS FOR PRELIMINARY PREDICTION Table 1

CONSEQUENCE OF OCCURRENCE CODE

A_c = Mission abortion

Bc = 90% mission aborts with reduced performance in remainder

C_c = 50% mission aborts, 30% reduced performance, and 20% unaffected

D_c = 20% mission aborts, 30% reduced performance, and 50% unaffected

E_c = No consequence

Table II

PROBABILITY OF OCCURRENCE CODE

A_p = 1 failure out of 5 possibilities for failure

B_p = 1 failure out of 10 possibilities for failure

C_p = 1 failure out of 100 possibilities for failure

D_p = 1 failure out of 1000 possibilities for failure

E_p = 1 failure out of 10,000 possibilities for failure

APPENDIX A

MTBF AS A RELIABILITY MEASURE OF MERIT

The following assumptions are basic and obligatory when MTBF Mean Time Between Failures) is employed as a unit of measurement for reliability. Mathematically, MTBF is defined in the equation

$R = e^{-T/M_o}$ where R is the desired probability of success,
e is the base of naperian logarithms
T is the length of time for which failure-free operation is desired
M_o is mean time between failures

Assumption 1 -- It is assumed that there exists a constant hazard rate for the equipment under test for the entire period during which data are gathered; i.e., there is no wearout occurring in the equipment. Since no wearout is assumed, 1000 equipments which individually operate without failure for one hour provide equal proof of reliability that one equipment which operates successfully for 1000 hours does.

Assumption 2 -- It is assumed that all failures are random; i.e., that their frequency of reoccurrence and the severity of their effect cannot be predicted. In practice, this assumption is generally interpreted as meaning that random failures occurring are "one-time-never-to-occur-again" failures. Further, they are often treated as a class of failures differentiated from a class of wearout failures and, thereby, "random" is equated to be a *cause* of failure as wearout truly is.[10]

Assumption 3 -- It is assumed that the environment in which the equipment is operating during the entire period in which data are gathered is identical in every respect, including concurrent stresses such as vibration, shock, temperature, humidity, altitude, and constant acceleration loading, with the environment which the equipment will see in service.[10]

Assumption 4 -- It is assumed that, upon repair of any failure, 100 percent restoration of life for the entire equipment occurs; e.g., an equipment which operates successfully for 560 hours before the first failure will, after the repair of that first failure regardless of its magnitude, be in exactly the same condition that it was prior to the start of the 560 hour period. This assumption follows from Assumption 1.

Assumption 5 -- It is assumed that all failures are of equal consequence to successful performance; i.e., it is immaterial in the compilation of data whether the equipment explosively disintegrated or whether some performance parameter momentarily drifted out of tolerance by one percent.

Assumption 6 -- It is assumed that all failures are independent in both cause and effect; i.e., each failure can be totally isolated and repaired, and no other portion of the equipment will have suffered the least degradation as a result of this failure. This assumption follows partially from Assumptions 1 and 4.

(Continued on page 24)

DESIGN for MANNED REENTRY GLIDE

Raymond J. Comenzo and Lawrence D. Wing
Advanced Programs Group, The Martin Company

Concluded from the October Issue

Turning now to the heat flux on the blunt noses and wing leading edges, the equilibrium wall temperature at the stagnation point is shown parametrically in Fig. 5. The stagnation point temperature parameter is $T_w R^{1/8} \epsilon^{1/4}$, where R = the nose radius and ϵ the surface emissivity. This parameter may be seen to be a function only of vehicle altitude and velocity and derives from the work of Dr. Dean Chapman (Ref. 1).

The stagnation point temperature of a specific vehicle is found by determining the altitude and velocity at the time of interest, extracting the temperature parameter value corresponding to these flight conditions from Fig. 5 and dividing this figure by the product of the 1/8 power of the radius and the 1/4 power of the surface emissivity.

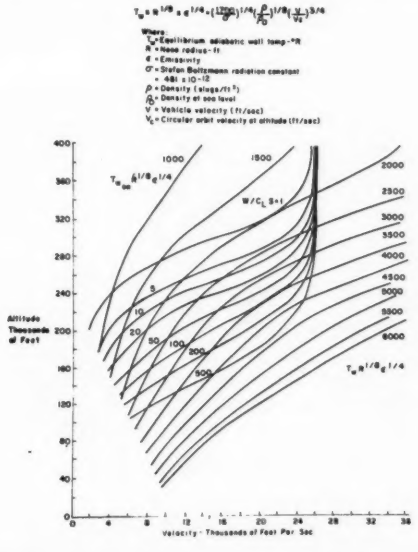


Fig. 5. Stagnation Nose Temperature and W/C_LS as Functions of Altitude and Velocity

Figure 5 also contains lines of altitude and velocity relationships for the equilibrium glide of vehicles having various values of the aerodynamic parameter, W/CLS, where W is the vehicle weight, S is the wing area and C_L the lift coefficient. By the following any one of these W/C_LS lines, the stagnation point temperature parameter at any altitude and velocity may be obtained by interpolating between the temperature parameter lines.

Temperatures so derived are extremely accurate for nose radii of one foot or greater and may be used for determining leading edge stagnation point temperatures (even on swept-back wings) by applying simple correction factors.

From Fig. 5 it can be seen that at high velocities (19,000 to 23,000 fps), the temperature parameter and vehicle equilibrium glide path converge--while in the lower velocity region they diverge. It is significant to note here that the vehicle acceleration is not a uniquely significant factor for winged reentry vehicles. This is because the decelerations that can occur during flight, with the temperature limits imposed by material capabilities, are never of sufficient magnitude to present any serious threat either to the vehicle or its crew--except with respect to the vehicle maneuver capability in the lower altitude portion of flight.

It is advisable, at this point, to examine the method of estimating blunt nose and leading edge thermal inputs more closely. The stagnation point temperature parameter ($T_w R^{1/8} \epsilon^{1/4}$) lines of Fig. 5 are obtained (Ref.1) from the solution of

$$q_t = \frac{17{,}000}{\sqrt{R}} \sqrt{\frac{\rho}{\rho_o}} \cdot \left(\frac{V}{V_c}\right)^3 \qquad (2)$$

and the radiation relationship: $q = \epsilon \sigma T_w^4$. The two q values are equated and the resulting equation solved for $T_w R^{1/8} \epsilon^{1/4}$.

The equilibrium glide lines of Fig. 5 result from the solution (Ref. 1) of the approximate equation:

$$V \approx \left[\frac{W/C_L S}{\frac{W}{C_L S V_c^2} + \frac{\rho}{2}} \right]^{1/2} \qquad (3)$$

The velocities assumed for the solution of this equation are relative to the air mass through which the vehicle is passing. A check of the approximate curves of Fig. 5 with exact solutions, which are considerably more complicated, has shown a maximum error of less than 3% over the range of applicability of Fig. 5.

Having obtained a stagnation point temperature parameter from Fig. 5 for the desired altitude and velocity, the parameter is reduced to an equilibrium wall temperature by dividing by an appropriate $R^{1/8}\ \epsilon^{1/4}$. The temperature is then converted to a q value by solving $q = \epsilon\ \sigma T_w^4$. This q represents the stagnation point heat transfer rate to a hemispherical nose having the applicable radius and surface emissivity. The distribution of heat transfer rate around the nose may now be obtained from the above q stagnation and the appropriate curve of Fig. 6.

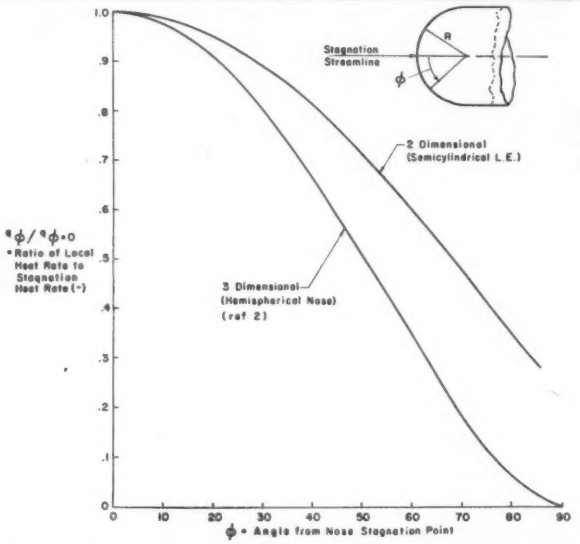

Stagnation Streamline
R
ϕ
2 Dimensional (Semicylindrical L.E.)
3 Dimensional (Hemispherical Nose) (ref 2)
qϕ/qϕ=0 = Ratio of Local Heat Rate to Stagnation Heat Rate (-)
ϕ = Angle from Nose Stagnation Point

Fig. 6. Distribution of Heating to a Hemispherical Nose and a Semicylindrical Leading Edge

For a semicylindrical leading edge, the temperature parameter is obtained from Fig. 5 and converted to a stagnation point temperature by dividing by $R^{1/8}\epsilon^{1/4}$. Thence, q stagnation is obtained from $q_s = \epsilon\sigma T_w^4$ as above. However, the q thus obtained must be corrected from three-dimensional to two-dimensional flow by the relationship* q_2 dimen/q_3 dimen = 0.65.

Again, the heat transfer rate distribution around the leading edge is obtained from the (two-dimensional) stagnation q and the appropriate curve of Fig. 6. Once the q distributions around either the nose or the leading edge are known, the equilibrium wall temperatures are available from

$$T_{w_{eq}} = \sqrt[4]{\frac{q}{\epsilon\sigma}}\ .$$

* This ratio has been assigned several values in the literature, but the value 0.65 has been found to yield the best results when applied to q's derived from Eq. (2).

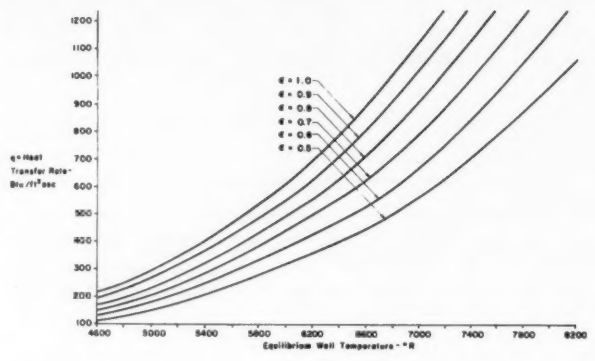


Fig. 7. Heat Transfer Rate Versus Equilibrium Wall Temperature

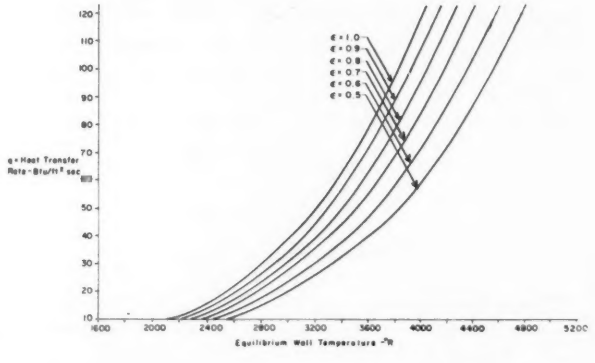
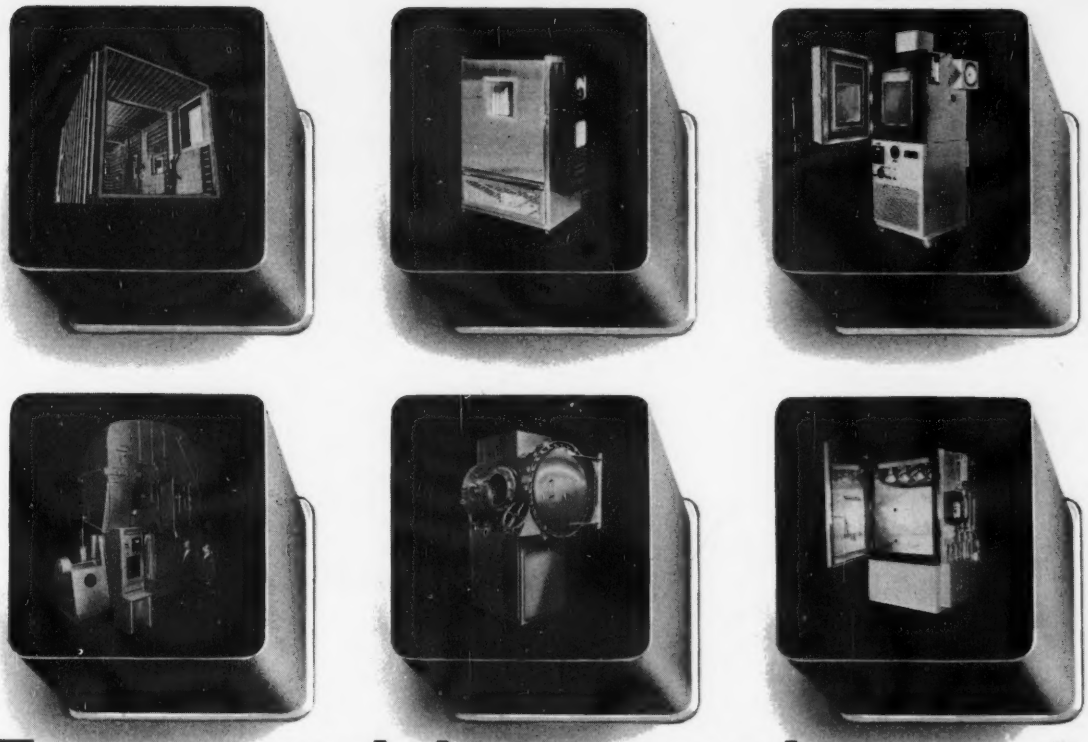


Fig. 8.
Heat Transfer Rate Versus Equilibrium Wall Temperature

It may be noted that this equation has been solved for a wide range of q and ϵ values and the plotted results (Figs. 7, 8, 9 and 10) are used to facilitate the transferring from heat rates to temperatures. Similarly, the term $R^{1/8}\ \epsilon^{1/4}$ is plotted against R for a family of ϵ values (Fig. 11).

To make this simplified analysis applicable to swept-back wings at angle of attack, three additional corrections are required. First it is necessary to correct the two-dimensional stagnation point heat transfer rate for the effect of the sweep-back angle (λ_{eff}). This is accomplished by means of Fig. 13, which shows the ratio of q at some λ_{eff} to q at $\lambda_{eff} = 0$.

It will be noted that Fig. 13 shows this ratio as a function of λ_{eff} since, when an angle of attack is introduced, the sweep-back angle (λ_{eff}) that the air stream "sees" is always less than the true geometric sweep-back angle (λ). Thus, before applying the cor-



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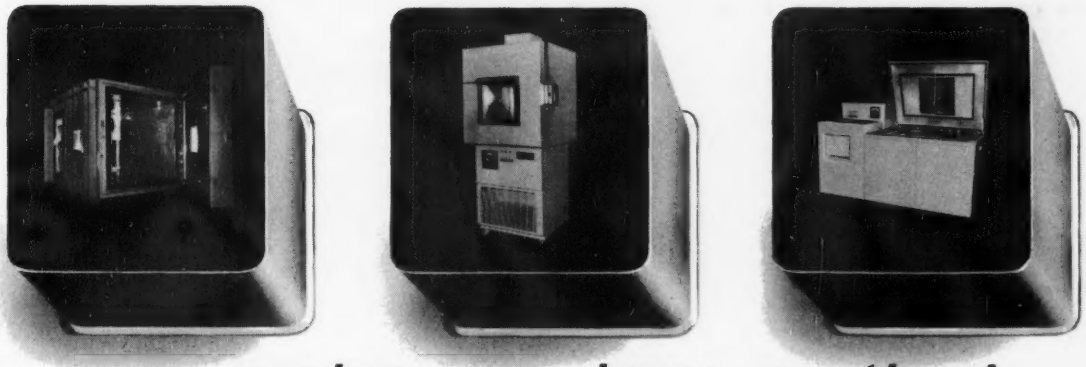

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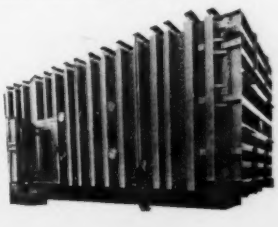

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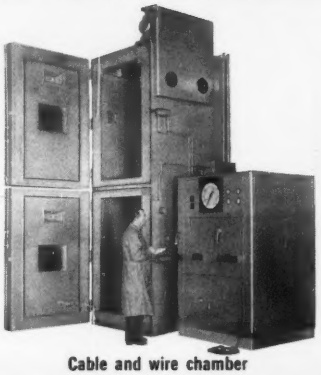
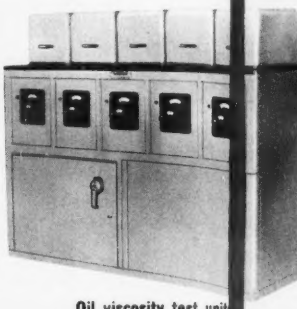
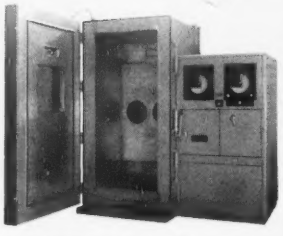


Cable and wire chamber



Oil viscosity test unit



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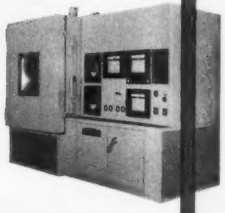
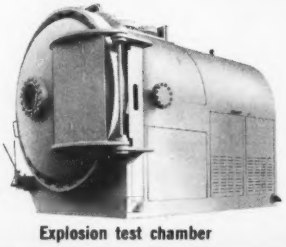
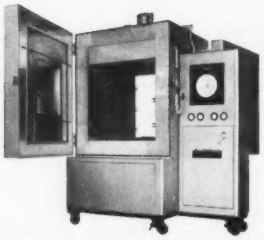


400,000 ft. altitude test chamber

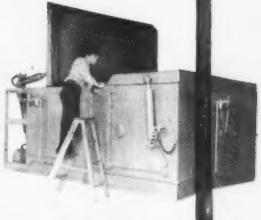


Explosion test chamber

Large altitude chambers



"Pass through" double duty units



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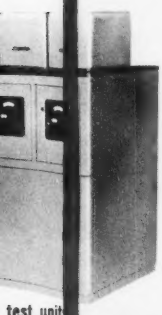
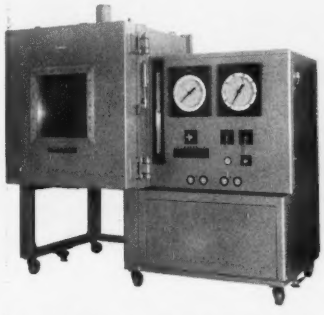


test unit



Altitude chamber with external shaker

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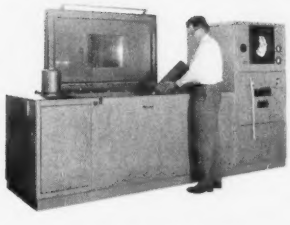

Concrete test chamber

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Packaged "walk-in" altitude test chambers

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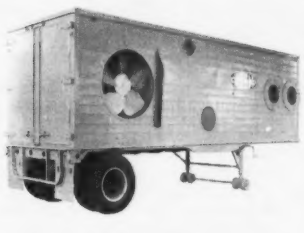

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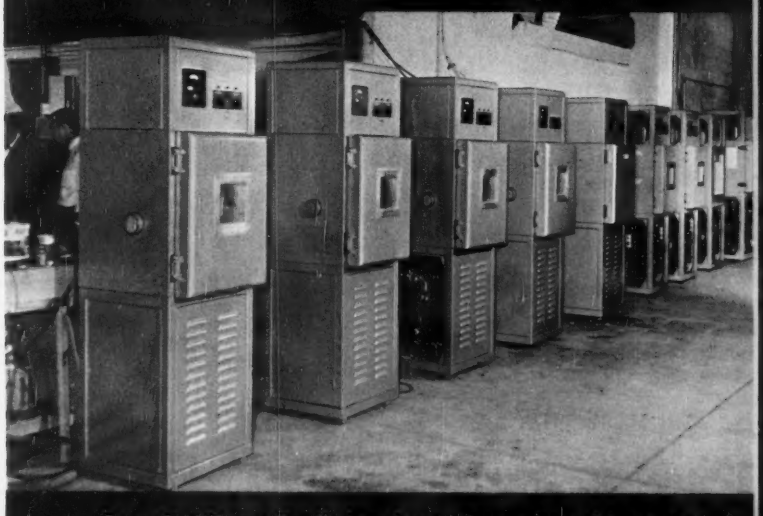

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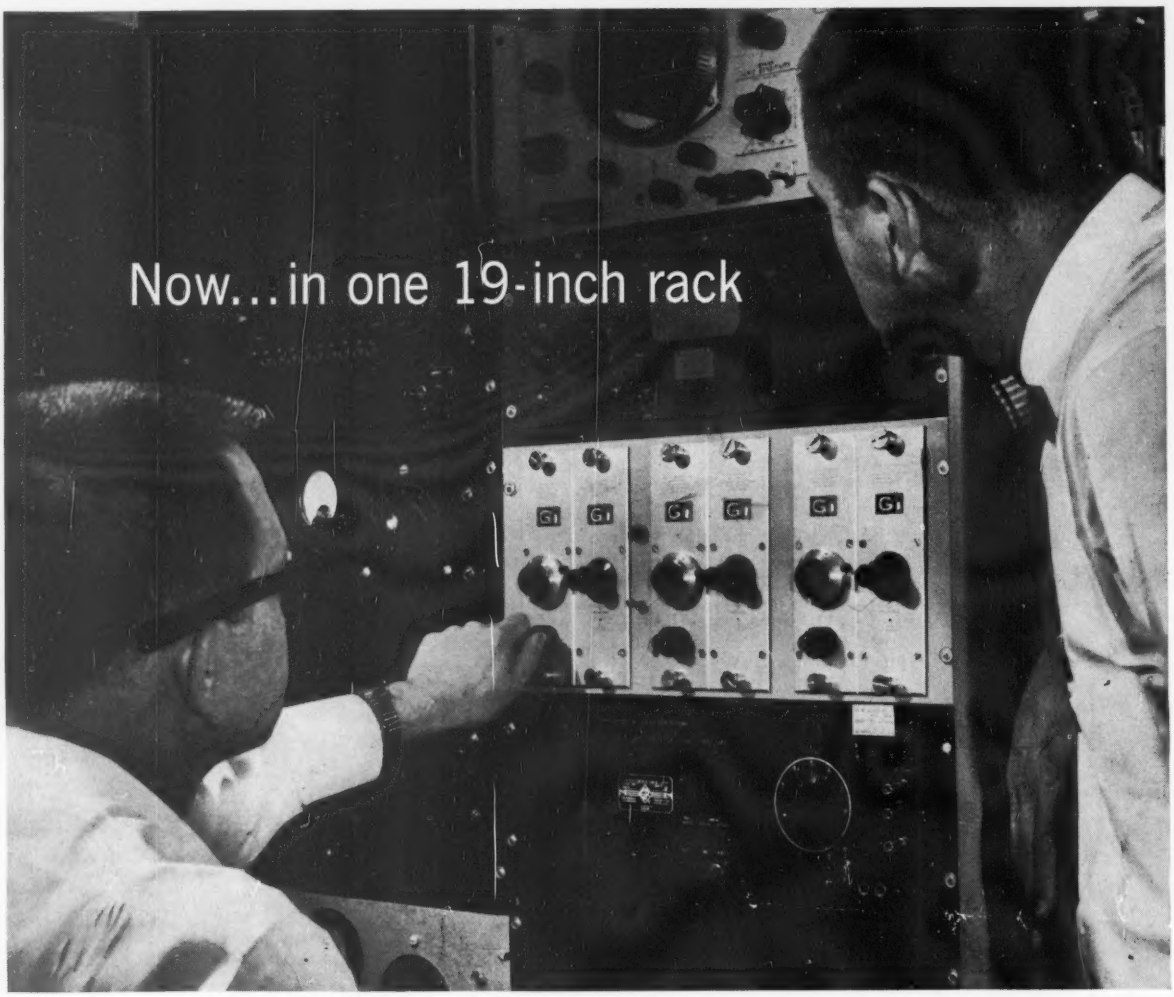

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Present models feature high input impedance and low loading, particularly suitable for piezoelectric transducers. Amplifier modules for other applications, integration, carrier systems, etc. will be available soon.

Precision Gain Control: Employing a precise 10 turn potentiometer and calibrated dial, the gain can be set and locked or continuously varied. Accurate calibration and excellent linearity permits immediate resetting to any desired gain level without need for additional checks.

Sensitivity control indicates gain and millivolts per unit of measurement, i.e., in vibration measurements, mv/g. This arrangement provides a convenient means for measuring "g" levels and calibration of accelerometers.

Maximum Reliability — Minimum Maintenance: All-transistorized current amplifier and hybrid circuit voltage amplifier provide maximum reliability with optimum performance. Reduced power consumption means less heat generation, lowest maintenance factor.

For complete details and specifications, write Instrumentation Division, Gulton Industries, Inc.

SPECIFICATIONS

	Voltage Amplifier	Galvanometer Amplifier
Gain:	variable 0.5 to 500	variable 0.05 to 3
Gain Accuracy:	better than 3% of reading	not calibrated
Gain Stability:	better than 1%	max. drift 2 mv/°F
Frequency Response:	±10% 10cps to 20KC	±5% 10cps to 10KC
Input Impedance:	75 megohms, min.	25,000 ohms
Noise:	less than 500 u v rms, rti	negligible
Output Voltage:	5 volts rms into 25 K load	±100 ma into 35 to 100 ohm load
Linearity:	better than 2%	better than 2%

GI® INSTRUMENTATION DIVISION

Gulton Industries, Inc. Metuchen, New Jersey

In Canada: Titania Electric Corp. of Canada, Ltd., Gananoque, Ont

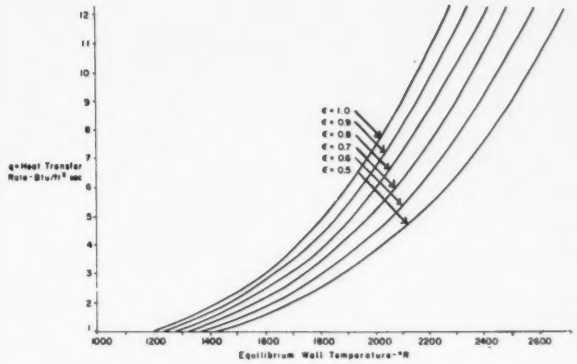


Fig. 9.
Heat Transfer Rate Versus Equilibrium Wall Temperature

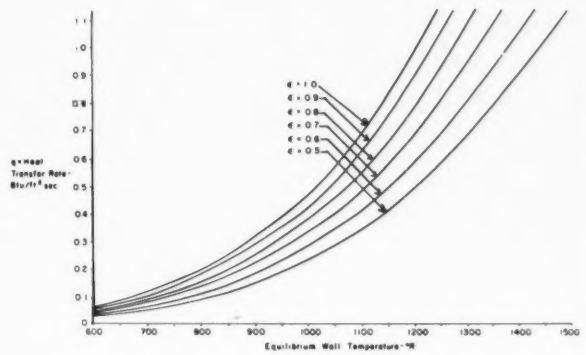


Fig. 10.
Heat Transfer Rate Versus Equilibrium Wall Temperature

rection from Fig. 13, it is necessary to use Fig. 12 in which the geometric sweep-back angle (λ) and the angle of attack (α) are used to determine the effective sweep-back angle (λ_{eff}). Figure 12 derives from the relationship:

$$\text{Tan } \lambda_{eff} = \text{Tan } \lambda \cos \alpha \cos \beta \qquad (4)$$

where

$$\beta = \text{Tan}^{-1} (\sin \alpha \text{ Tan } \lambda)$$

It is now possible to proceed as described to find the q distribution over the wing leading edge, relative to the stagnation point location. However, at angles of attack, one must estimate the location of the stagnation point on the swept-wing leading edge. This may be accomplished by means of Fig. 14, which presents the solution of the geometric relationship:

$$\theta = \cos^{-1} \left[\frac{\cos \alpha \cos \lambda}{(\cos^2 \alpha \cos^2 \lambda \sin^2 \alpha)^{1/2}} \right] \qquad (5)$$

With the aid of Figs. 5 through 14, it is possible to quickly estimate the heat transfer rates or equilibrium wall temperatures over hemispherical noses or blunt, swept-back wing leading edges at angle of attack. These data, in combination with the wing lower surface heating data discussed above (and in the Addendum), enable the designer to arrive at a general thermal environment for the design of a manned reentry glide vehicle.

The use of the Chapman Eq. (2) in the derivation of Fig. 5 renders the data useless at altitude-velocity combinations which yield calculated surface temperatures in excess of the recovery temperatures for those flight conditions. For this reason, the temperature parameter lines in Fig. 5 have been abruptly discontinued in the lower ranges of altitude and velocity.

The results become less accurate as one moves from the peak velocity point toward the zero point of the V-h diagram on any temperature parameter line. The presence of slip or free molecular flow at the opposite ends of the temperature parameter lines also introduces errors. However, these two error regions occur well away from the region of maximum aerodynamic heat input--the portion of flight which is of primary concern in the design of the thermal protection system.

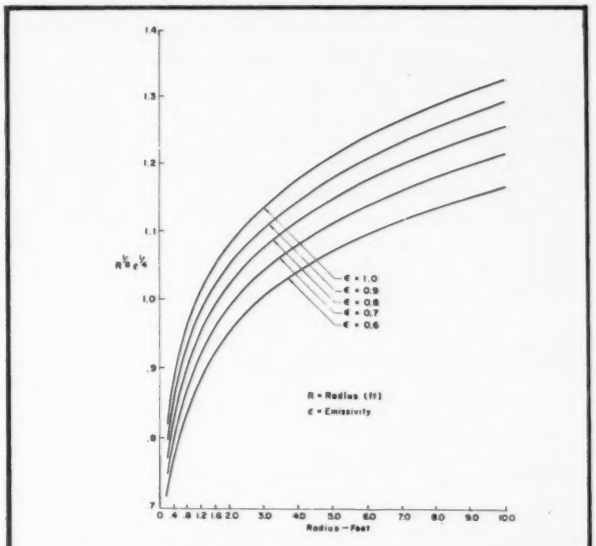


Fig. 11. $R^{1/8} \epsilon^{1/4}$ Versus R as a Function of ϵ

AIR CONDITIONING

Having discussed a simplified approach to estimating the magnitude of the available flight corridor for a glide reentry vehicle, it is of interest now to examine means of dealing with the severe thermal environment. This problem may be considered to have two facets: (1) the design of a structure capable of accommodating the high heat influx while maintaining the necessary structural integrity; and (2) the design of a means of protecting both crew and sensitive elements of equipment from the influx of heat into the vehicle compartments.

The second consideration is of interest here: the cabin air-conditioning and temperature regulating system. A typical glide reentry has been assumed for the purpose of estimating the heat inputs from aerodynamic heating.

To give the crew "living-room" comfort for "shirt-sleeve" operation, the cockpit ambient air temperature is maintained at 70° F and the cock-pit walls at 90° F. The primary structure is cooled to 200° F by a cooling system made up of coils in the wall structure through which an aqueous glycol solution is circulated. Low conductivity insulation will reduce the internal cockpit-wall temperature to 90° F. Owens-Corning Fiberglas (PF–319) is quite effective for this purpose, due to its low thermal conductivity and density.

The heat loads required to keep the cockpit at an ambient temperature of 70° F are tabulated as follows:

Component	*Heat Load (Btu/hr)*
Heat input, cockpit walls	2,630
Heat input, front window	320
Heat input, two side windows	380
Heat input, navigation aid window	1,070
Heat from instrumentation and equipment	3,600
Metabolic heat	500
Total	8,500

Vaporization of the liquefied gases (oxygen-nitrogen), which are required for pressurization, provides 765 Btu/hr of cooling capacity under the normal 1.8-cfm structural leakage (normal total leakage for cockpit and equipment and research compartment). Therefore, the total heat load for the cockpit air-conditioning system is 7,735 Btu/hr. However, the heat load is decreased to 6,800 Btu/hr when the liquefied gas input is 4 cfm (1,700 Btu/hr liquefied gas capability). The cockpit air-conditioning system is designed for 7,735 Btu/hr heat load.

Several systems have been considered for air conditioning the cockpit: (1) a liquid oxygen-nitrogen mixture, (2) liquid oxygen, (3) liquid nitrogen and (4) boiling water. The liquefied gases offer high reliability but result in a heavy system and have limited growth potential with increase in mission time (see Fig. 15). Therefore, a system utilizing water boiling at low pressure (and, consequently, at low temperature) is used as a primary heat sink to cool the circulating air.

The water boiling system offers a weight advantage over other systems for a typical 2-1/4-hour mission, and the advantage becomes greater with increase in mission time. Another feature is the high heat exchange per pound of coolant, since the latent heat of vaporization of water boiling at 40° F or lower is approximately 1,070 Btu/lb. However, additional study is required to evaluate the use of boiling water in a zero-gravity field and at low pressure.

The boiling water system utilizes a heat exchanger so designed that water boils in it at a maximum of 40° F (6.3 mm Hg). The heat exchanger is designed so that the water boils in a zero-gravity field by utilizing its own momentum for wetting heat exchanger surfaces.

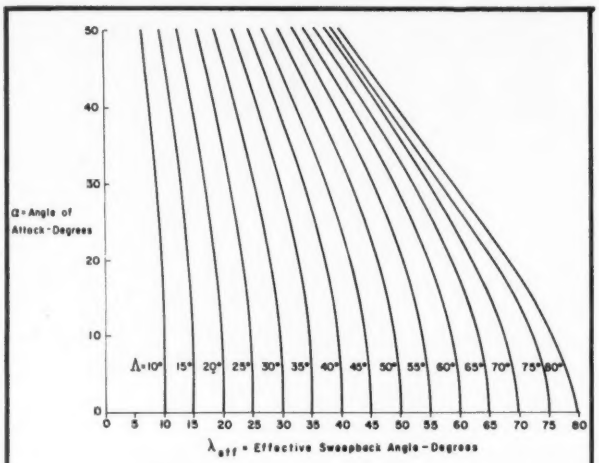


Fig. 12. Effective Sweepback Angle Versus Angle of Attack

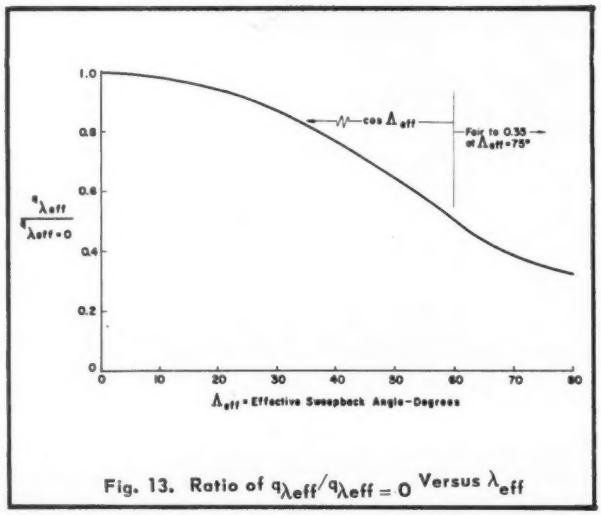


Fig. 13. Ratio of $q_{\lambda eff}/q_{\lambda eff = 0}$ Versus λ_{eff}

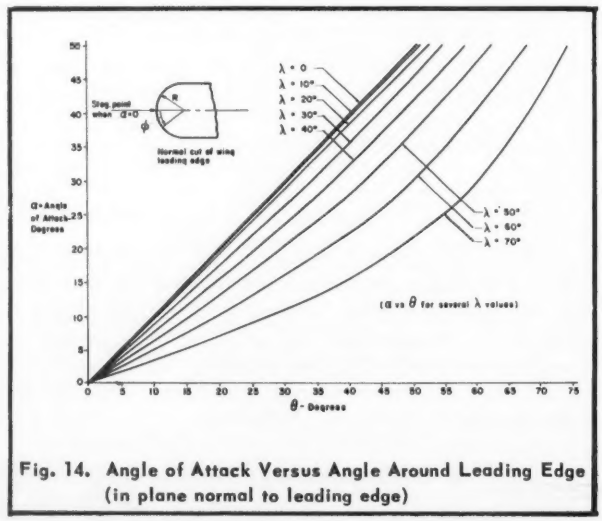

Stag. point when α = 0
Normal cut of wing leading edge
α = Angle of Attack, Degrees
λ = 0
λ = 10°
λ = 20°
λ = 30°
λ = 40°
λ = 50°
λ = 60°
λ = 70°
(α vs θ for several λ values)
θ - Degrees

Fig. 14. Angle of Attack Versus Angle Around Leading Edge (in plane normal to leading edge)

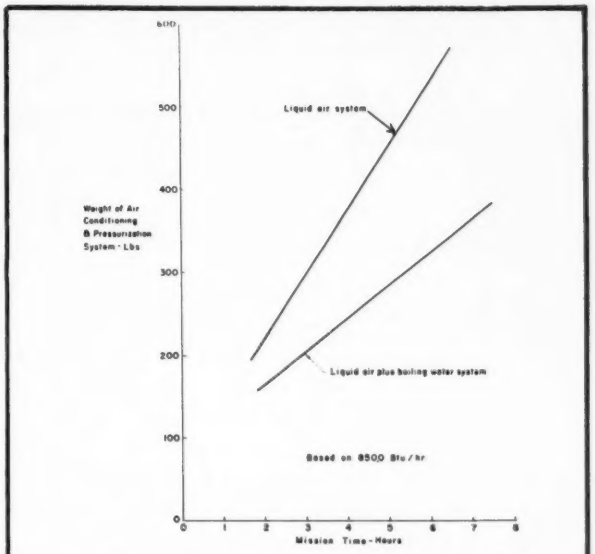


Fig. 15. Effect of Mission Time on Weight of Air Conditioning and Pressurization Systems

The air from the cockpit enters the heat exchanger at 70° F and is cooled to 41° F. A fan circulates the air at a rate of 460 cfm. Ducting is provided, so that high heat generating areas receive high air flow rates. The liquefied oxygen-nitrogen mixture provides ample cooling for the heat generated by the pilot. With proper ducting of this air at the waist, feet and shoulders, the pilot can be made quite comfortable.

Although both a liquid and an air cooling system have been considered for equipment cooling, the liquid offers several advantages over air. The higher specific heat and density of liquid means less flow and pressure drop. This allows lower pumping costs. In addition, the liquid offers better heat transfer characteristics, so that a more efficient system results.

The liquid must have a high specific heat and low viscosity, it must not freeze at -40° F and it must be available at minimum cost. A 60% aqueous propylene glycol solution is the most advantageous for this use. Moreover, it has 8% greater specific heat than ethylene glycol, so that the flow rate is decreased 8%.

Since 60% propylene glycol is the same coolant as that used in the structural cooling system, the same heat exchanger and pumps are utilized. Therefore, the equipment cooling system is directly integrated with the structural cooling system. A minimum of weight is added to the structural cooling system, since the equipment compartment requires a coolant flow rate of only 1,360 lb/hr, as compared to about 12,000 lb/hr for structural cooling. Moreover, the heat dissipated (16,920 Btu/hr) is only 5% of the heat load absorbed by the structural cooling system.

ADDENDUM

Development of the Method for Approximating Heating of Wing Lower Surfaces During Manned Reentry of a Glide Vehicle

Using Reynold's analogy between heat transfer and friction, the energy absorbed by the friction layer is equal to the product of the shear stress, τ, and the free stream velocity, V. One half of this energy will be carried away by the flow, and the other half will represent heat passing into the vehicle, q. Thus, $q \sim \frac{\tau V}{2}$.

A more detailed analysis of the boundary layer at hypersonic velocities leads to the laminar boundary layer equation of Hautsche and Wendt:

$$q = \frac{C_p (T_\infty - T_w) + \sqrt{Pr}\ \frac{V^2}{2}}{Pr^{3/2} V} \qquad \text{(A-1)}$$

Rearranging to: $\frac{q}{V\tau} = 0.5\, Pr^{-1/6} + \frac{C_p (T_\infty - T_w)}{Pr^{2/3} V^2}$ and

with $Pr \approx 0.7$,

we get: $\frac{q}{V\tau} = 0.53 - \frac{7600 (T_\infty - T_w)}{V^2}$.

Since typical values of V and ΔT are 20,000 fps and 1800° F, respectively, the second term has a value of approximately 0.034, from which the equation becomes $\frac{q}{V\tau} \approx 0.496$. However, these values are not exact, hence, the following simplification is reasonable:

$$\frac{q}{V\tau} \approx 0.5. \qquad \text{(A-2)}$$

The very low Reynolds Numbers associated with the extremely high speeds lead to the justifiable assumption of laminar flow. The lift required for steady hypersonic flight is:

$$L = W - \frac{MV^2}{r} = W \left(1 - \frac{V^2}{V_c^2}\right) \qquad \text{(A-3)}$$

since

$V_c = \sqrt{gr}$ = satellite velocity, but $L = 1/2 \rho V^2 C_L S$

so that $\frac{\rho V^2}{2} = \frac{W}{C_L S}\left(1 - \frac{V^2}{V_c^2}\right)$. (A-4)

Introducing the Reynolds Number (per foot):

$$\frac{\rho V}{\mu} = \frac{2}{\mu V}\ \frac{W}{C_L S}\left(1 - \frac{V^2}{V_c^2}\right) . \quad \text{(A-5)}$$

But at a temperature of 400° R, the viscosity is about 3×10^{-7} lb-sec/ft^2, and for

$$V \approx 20{,}000 \text{ fps}, \quad 1 - \frac{V^2}{V^2} \approx 0.4 \text{ so } \frac{\rho V}{\mu} \approx 130 \frac{W}{C_L S} .$$

Since transition Reynolds Numbers are probably above 10^7 at hypersonic speeds, it would take a very large value of $\frac{W}{C_L S}$ to cause turbulent flow; hence, the assumption of laminar flow. For laminar incompressible flow, the Blasius formula yields the wall shear stress

$$\tau = \frac{0.664}{\sqrt{Re}} \cdot \frac{\rho V^2}{2} = 0.332 \sqrt{\frac{\rho \mu}{X}}\ V^{3/2} . \quad \text{(A-6)}$$

The applicability of this equation to compressible flow, if the values of ρ and μ are taken at the wall, has been shown by Hautsche, Wendt and Chapman. From the gas equation, $\rho = \frac{p}{RT}$, and the assumption that the viscosity is a function of temperature only, described by the power law $\frac{\mu}{\mu_o} \approx \left(\frac{T_w}{T_o}\right)^{0.7}$, we get

$$\frac{\rho_w}{\mu_w} = \frac{P_w \mu_0}{R^* T_o^{0.7} T_w^{0.3}} . \quad \text{(A-7)}$$

For temperatures of 400° R, $\frac{\mu_o}{T_o^{0.7}}$ is about 4.6×10^{-9}

so that $\sqrt{\rho_w \mu_w} = \frac{1.64 \times 10^{-6} \sqrt{p_w}}{T_w^{0.15}}$. (A-8)

If the aerodynamic phenomena are assumed to occur only on the lower wing surface (since even at moderate incidence the upper surface is virtually unaffected by the stream) and the pressure on the wing is assumed to be uniform, then

$$p_w = \frac{W}{S}\left(1 - \frac{V^2}{V_c^2}\right) . \quad \text{(A-9)}$$

Combining Eqs. A-1, A-6, A-8 and A-9, the heat flow into the wall becomes:

$$q = 0.272 \times 10^{-6} \sqrt{\frac{W}{SX}}\ V^{5/2} \sqrt{1 - \frac{V^2}{V_c^2}}\ T_w^{-0.15} \quad \text{(A-10)}$$

The maximum heating rate occurs where $V^5\left(1 - \frac{V^2}{V_c^2}\right)$ is minimum or when $V = 0.845\ V_s = 21{,}700$ fps

in which case $q_{max} \approx 10^4 \sqrt{\frac{W}{SX}}\ T_w^{-0.15}$ (A-11)

From the radiation equation $q_{rad} = \epsilon \sigma T_w^4$ and $\sigma = 3.75 \times 10^{-10}$ and the assumption of an emissivity (ϵ) of 0.8, the heat radiated away from the surface is

$$q_{rad} \approx 3 \times 10^{-10}\ T_w^4 \quad \text{(A-12)}$$

If an adiabatic wall is assumed, then the q values of Eqs. A-11 and A-12 may be equated and reduced to the form:

$$T_{w_{max}} = 1810 \left(\frac{W}{SX}\right)^{0.1205} \quad \text{(A-13)}$$

The foregoing development has resulted in the curves of Figs. 3 and 4 was taken from the work of Hans Multhopp (Ref. 3).

SYMBOLS

C_L	lift coefficient
M	vehicle mass
P	pressure
Pr	Prandtl number
q	heat transfer rate
r	distance from center of earth
R*	gas constant for air
Re	Reynolds number
R	radius of hemispherical nose or semicylindrical leading edge
S	wing area
T	temperature
V	vehicle velocity (relative to air)
V_c	circular orbit satellite velocity at appropriate altitude
W	vehicle weight
X	distance from leading edge
α	angle of attack
ϵ	surface emissivity

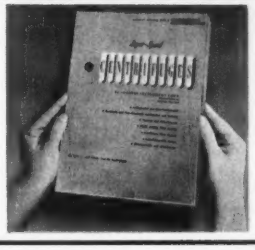
(Continued on page 27)

NEW PRODUCTS

NEW LOURDES COMPLETE-LINE CENTRIFUGE CATALOG

Lourdes Instrument Corp., a division of Labline, Inc., has announced publication of a completely new and up-dated catalog on its full line of centrifuges and homogenizers.

The catalog is a 16-page, fully illustrated book designed to offer finger-tip reference to the complete line manufactured by Lourdes. It also lists in detail the rotors and attachments produced for each model.

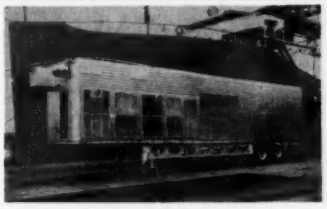


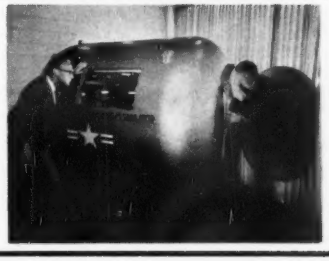
Refrigerated and non-refrigerated models are shown, as well as vacuum and non-vacuum centrifuges. Full details are given on all floor and bench models of both the automatic and non-automatic type.

To obtain this new No. 260 catalog, write Lourdes Instrument Corp., 53rd Street and First Avenue, Brooklyn 32, New York.

ENVIRONMENTS TO ORDER . . . ON WHEELS

This 30-ton, 46-foot semi-trailer van provides extreme environmental conditions for testing missile parts when and where needed, even on a launching pad. Manufactured by Tenney Engineering, Inc., Union, N. J., world's oldest and largest manufacturer of environmental test equipment, the simulator is shown prior to being loaded on board a ship enroute to the White Sands, N. M., Proving Grounds. Despite outside weather from -5° to +115° F., extreme solar radiation, two inches of rainfall an hour, or a sand and dust storm whipping about at 75 m.p.h., the self-contained mobile giant can simulate and hold such combined climatic extremes as: -85° to +200° F., relative humidity of 20 to 100 per cent, and air flow of 600 to 6,000 cfm.





SPACE SIMULATOR TEST CAPSULE

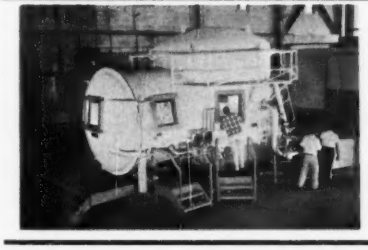
Mock-up of a test capsule, to be used by the Air Force to simulate flight in space, was displayed for the first time by Garrett's AiResearch Manufacturing Company of Los Angeles during the Air Force Association's convention in San Francisco, September 21 - 25. The actual space simulator will enable the Air Force to study, for the first time, various effects of space flight, including stresses of high altitude, accelerations, heat and isolation. In addition, the capsule will provide a laboratory tool to test man's physiological limitations under environmental conditions potentially imposed by space flight; plus evaluate the operation and performance of space life support systems and components. The capsule is designed for testing in an altitude chamber, centrifuge or in heat or cold chambers.

NEW PROTECTIVE SUIT FROM FILTRON SHIELDS AGAINST RADIATION

An RF radiation protective suit that affords complete protection from the harmful biological effects of electromagnetic radiation has been perfected by the Filtron Company, Inc., Flushing, N. Y. Tradenamed the ATTENU-SUIT, this new one-piece garment has a shielding effectiveness of 50 DB over a frequency range from 30 MC to 1000 MC, and is arc resistant to a potential up to 4000 volts.

Tests show the protective suit can be safely worn in areas where the RF level is 10,000 times greater than the USAF maximum safe limit of 10 milliwatts per square centimeter.

For additional information, contact the Systems Engineering Division, Filtron Co., Inc., Flushing, New York, telephone HIckory 5-7000.



TENNEY ENGINEERING'S 'MERCURY POD' GIVES ASTRONAUTS A TASTE OF SPACE

Tenney Engineering, Inc.'s unique Project Mercury high altitude simulator has been installed at Cape Canaveral, Fla., to get U.S. astronauts accustomed to living in space. It will "rise" to an altitude of 225,000 feet, or roughly 45 miles.

In its main, kettle-like section, which is 12 feet in diameter and 15 feet high, the simulator, dubbed "Mercury Pod" by Tenney engineers who built it, will accommodate the capsule in which the first American space man is expected to soar into orbit.

The simulator's vacuum system will provide dive rates of up to 50,000 feet a minute. But in an emergency, the chamber will be able to reach sea level from 225,000 feet in six seconds.

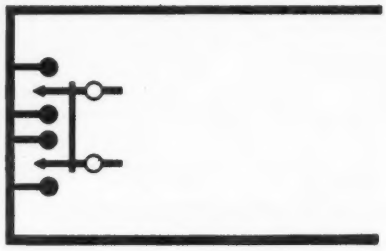
NEW GLENNITE ACCELEROMETER BROADENS USEFUL FREQUENCY SPECTRUM

A unique subminiature accelerometer, which broadens the useful frequency measurement spectrum by over 25 per cent, has been announced by Robert G. Day, Manager of Gulton Industries Instrumentation Division.

Weighing only 4 grams, the new Glennite accelerometer, Model AA-1220, has a resonant frequency of 125 KC, providing a useful frequency range to 25 KC. It can be used to measure acceleration levels up to 15,000g.

Special design of the seismic element minimizes any DC shift in both axes even at high acceleration levels. The transverse response is less than 3%.

TECHNICAL INFORMATION



CONDENSER MICROPHONES IN HIGH ALTITUDE ENVIRONMENTS

B & K Instruments, Inc., 3044 West 106th Street, Cleveland 11, Ohio, announces the release of a Technical Review on "Pressure Equalization of Condenser Microphones and Performance at Varying Altitudes". To obtain a copy request TR-1, 1960.

IES PUBLICATIONS FOR SALE:

1959 PROCEEDINGS

54 papers presented at the 1959 National Meeting of the IES in Chicago, Illinois. Volume is well illustrated and covers earth and space environments, reliability, instrumentation, ground support equipment.

Members $8.00; Non-Members $12.00

1960 PROCEEDINGS

Papers presented at the 1960 National Meeting of the IES in Los Angeles, California. Volume is well illustrated and covers earth and space environments, biology, reliability, space vehicles, instrumentation.

Members $8.00; Non-Members $12.00

1960 REPRINTS

Reprints of each paper presented at the 1960 National Meeting and published in the 1960 Proceedings.

Each Reprint $0.50 each

Any of the above material can be ordered from the National Office address, IES, Box 191, Mt. Prospect, Ill.

The Transit Satellite Thermal Vacuum Test Program by R.W. BLEVINS, L.D. ECKARD & I.B. IRVING; Applied Physics Laboratory, The Johns Hopkins University.

The test program and equipment used in the combined thermal-vacuum environment is described. Emphasis will also be given to the design and construction techniques used to put this facility into operation.

Laboratory Simulation of Solar Radiation by D. ASKIN & J. WILAND; U.S. Army Ordnance, Frankford Arsenal.

This paper describes a new approach to the simulation of solar radiation. It discusses previous methods of such simulation and describes in detail the requirements for such a facility.

Horizontal Shock Apparatus by W. H. GRUMET; American Laboratories Division, American Electronics, Inc.

Commonly applied air transportability specifications such as MIL-A-8421A require the application of a nominal acceleration applied for a period of approximately 0.1 second. This paper describes a novel method for obtaining such a pulse on a large equipment to simulate the "emergency landing loads test" requirement in current specifications.

A Heat Pulse Oven for Study of Human Thermal Tolerance by J. F. CROCKER & J. H. VEGHTE; Wright Air Development Division, ARDC.

A four foot cube chamber with thin aluminum walls heated by quartz tube infrared lamps has been built to simulate the thermal surroundings of the crew of a hypersonic vehicle re-entering the earth's atmosphere. Human tolerance to peak wall temperatures as high as 500°F and air temperatures of 432°F has been explored. Results are presented and protective measures are discussed.

Space Equipment Environmental Facility by Maj. J. J. ROSA; Occupational Health Research Laboratory, Patrick Air Force Base.

Assuming that space flight projects will prove practical, necessary, and continuous, a completely integrated space-equivalent environmental facility would be invaluable in supporting present and future man-in-space projects. General considerations of such a facility as part of a long range research and development program are outlined.

Space Environment Facility for Life Support Systems by O. SCHUELLER; Wright Air Development Division, ARDC.

Proposal is presented for the design of a test facility for reproduction of some characteristic hyper-environments in manned space flight and in the exploration of the moon. Details of a facility consisting of a combination of three interconnected chambers are presented.

Random-Sine Vibration Equivalence Tests of Missile Equipment by H.R. SPENCE; Space Technology Laboratories.

Experimental data on random-sine vibration equivalence, based on RMS acceleration responses, was obtained for typical missile electronic packages. The results are presented with interpretations as to the significance of the findings.

Sweep Random Vibration by G.B. BOOTH; MB Electronics, Inc.

A new random vibration test procedure which accelerates setup and permits testing with equipment of greatly reduced cost.

(Continued on page 27)

NOTES FROM THE EDITOR

CHARLES W. DANIELSON
TECHNICAL EDITOR

Considerable confusion has developed regarding the publications which have been or are current in the Environmental field.

The following information has been compiled by the President of the Institute of Environmental Sciences, William L. Vandal, with some corrections and additions from my files.

There are three current publications in the Environmental field.

1. THE JOURNAL OF ENVIRONMENTAL SCIENCES
11916 West Washington Boulevard
Los Angeles 66, California
Del Guthrie, Publisher
Charles W. Danielson, Technical Editor
Official Publication of The Institute of Environmental Sciences, William L. Vandal, President

A. Published issues of THE JOURNAL OF ENVIRONMENTAL SCIENCES.
Vol. 3, No. 6, December 1960
Vol. 3, No. 5, October 1960
Vol. 3, No. 4, August 1960
Vol. 3, No. 3, June 1960
Vol. 3, No. 2, April 1960
Vol. 3, No. 1, February 1960
Vol. 2, No. 6, December 1959
Vol. 2, No. 5, October 1959

B. Previously published as: JOURNAL OF ENVIRONMENTAL ENGINEERING
Sponsored by: Society of Environmental Engineers (Not in existence)
Vol. 2, No. 4, August 1959
Vol. 2, No. 3, June 1959
Vol. 2, No. 2, April 1959
Vol. 2, No. 1, February 1959
Vol. 1, No. 2, December 1958
Vol. 1, No. 1, October 1958

Correspondence pertaining to the Journal should be sent to the Journal address. Matters related to the Institute of Environmental Sciences should be sent to H.F. Sander, I.E.S., Box 191, Mt. Prospect, Illinois.

2. THE ENVIRONMENTAL QUARTERLY
252-46 Leeds Road
Little Neck 62, New York.
Independently published, four times a year by: Environmental Publications Inc.
Martin Z. Post - Editor and Publisher

A. Published issues as an independent organization:
Vol. 6, No. 4, October 1960
Vol. 6, No. 3, July 1960
Vol. 6, No. 2, April 1960
Vol. 6, No. 1, January 1960
Vol. 5, No. 4, October 1959
Vol. 5, No. 3, July 1959
Vol. 5, No. 2, April 1959
Vol. 5, No. 1, January 1959

B. Previously published issues when associated with the Environmental Equipment Institute (still in existence) and the Institute of Environmental Engineers (not in existence)
Vol. 4, No. 4, Fourth Quarter 1958
Vol. 4, No. 3, Third Quarter 1958
Vol. 4, No. 2, Second Quarter 1958
Vol. 4, No. 1, First Quarter 1958
Vol. 3, No. 4, Fourth Quarter 1957
Vol. 3, No. 3, Third Quarter 1957
Vol. 3, No. 2, Second Quarter 1957
Vol. 3, No. 1, First Quarter 1957
Vol. 2, No. 4, Fourth Quarter 1956
Vol. 2, No. 3, Third Quarter 1956
Vol. 2, No. 2, Second Quarter 1956
Vol. 1, No. 2, January 1956 (Correct, not a misprint)
Vol. 1, No. 1, Fall 1955

3. TEST ENGINEERING
P.O. Box 286
Oakhurst, New Jersey
Independently published monthly by: The Mattingley Publishing Co.
Ray Mattingley, Editor and Publisher
Vol. 4, No. 5, November 1960
Vol. 4, No. 4, October 1960
Vol. 4, No. 3, September 1960
Vol. 4, No. 2, August 1960
Vol. 4, No. 1, July 1960
Vol. 3, No. 6, June 1960
Vol. 3, No. 5, May 1960
Vol. 3, No. 4, April 1960
Vol. 3, No. 3, March 1960
Vol. 3, No. 2, February 1960
Vol. 3, No. 1, January 1960
Vol. 2, No. 4, December 1959
Vol. 2, No. 3, November 1959
Vol. 2, No. 2, October 1959
Vol. 2, No. 1, September 1959
Vol. 1, No. 6, August 1959
Vol. 1, No. 5, July 1959
Vol. 1, No. 4, June 1959
Vol. 1, No. 3, May 1959
Vol. 1, No. 2, April 1959
Vol. 1, No. 1, February 1959
Mr. Mattingley previously was Editor of the Environmental Quarterly.

4. ENVIRONMENTAL ENGINEERING (not in existence)
Only one issue was published by the Institute of Environmental Engineers, before they merged with the Society of Environmental Engineers to form the Institute of Environmental Sciences.
Vol. 1, No. 1, February 1959
The Institute of Environmental Sciences also publishes a proceedings of their National Technical meetings held in the spring of each year. These are advertised in the Technical Information section of the Journal.

THE PRESIDENT'S CORNER

The Fall Executive Board meeting was held in Oakland, California in November just preceding the Shock and Vibration Symposium. Several items of routine business were considered and a great deal of information was exchanged between the National Directors of the various chapters as to types of programs being conducted, results of tours, progress of educational programs, etc.

Our Institute is still growing steadily. There are currently eleven chapters. These are located in Boston, New York City, Mid-Atlantic (Philadelphia, Baltimore, and Washington, D.C.), Northern Ohio, Detroit, Chicago, Southern Tier (New York State), San Diego, Los Angeles, Northern California (San Francisco), and Northwest (Seattle, Washington). A new chapter is in the process of being formed in Denver and increased activity of IES members in Washington, D.C. may result in a split of that group from the Mid-Atlantic Chapter if their current membership drive is successful.

A report from the 1961 National Meeting Committee indicated excellent progress and an outstanding technical program for that meeting in April in Washington, D.C. This meeting will continue the format of three parallel simultaneous sessions for a three day period (April 5, 6 and 7). Facilities for the exhibitors are better than ever and a good show of the latest in environmental testing facilities is assured.

On February 1st our Executive Secretary, Mr. Hank Sander, will determine membership levels in each chapter. A chapter qualifies for one National Director for each 150 members or part thereof, except that the minimum number of members is established at 25. From 25 to 150 members the chapter is entitled to one National Director. From 151 to 300 they have two and from 301 to 450 they have three. Chapters are urged to start their membership drives now so that they can qualify for as many directors as possible.

Election of National Officers will be held by mail ballot in March. The Nominating Committee this year consists of the eleven chapter presidents with the National President as Chairman. Discuss your recommendations with your chapter presidents now so that the Nominating Committee can present the best possible slate of officers for election in 1961.

Congratulations to Bob Geiger of the Northern California Chapter on his election to Fellow grade. He was elected at the November meeting and is very deserving of this honor.

Best of Season's Greetings to Everyone.

Bill Vandal

(Continued from page 10)

APPENDIX C
COMBINED RANKING SCALE
(in order of decreasing importance)

1. $A_p A_c$	14. $D_p B_c$	
2. $A_p B_c$	15. $C_p C_c$	
3. $B_p A_c$	16. $B_p E_c$*	
4. $A_p C_c$	17. $E_p B_c$	
5. $C_p A_c$	18. $C_p D_c$	
6. $B_p B_c$	19. $D_p C_c$	
7. $A_p D_c$	20. $C_p E_c$*	
8. $D_p A_c$	21. $E_p C_c$	
9. $A_p E_c$*	22. $D_p D_c$	
10. $B_p C_c$	23. $D_p E_c$	
11. $C_p B_c$	24. $E_p D_c$	
12. $E_p A_c$	25. $E_p E_c$	
13. $B_p D_c$		

*Indicates a combination of academic rather than practical possibility

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11. Whyte, William H. Jr., THE ORGANIZATION MAN, (1956), Doubleday and Company, Incorporated, Garden City, New York.

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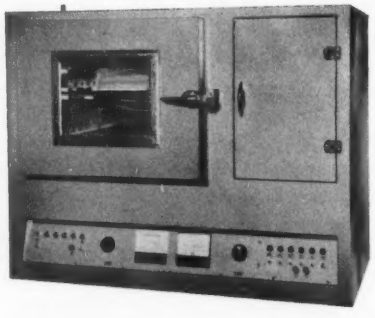

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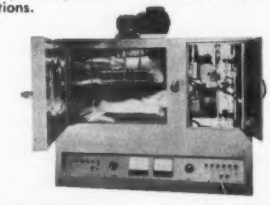

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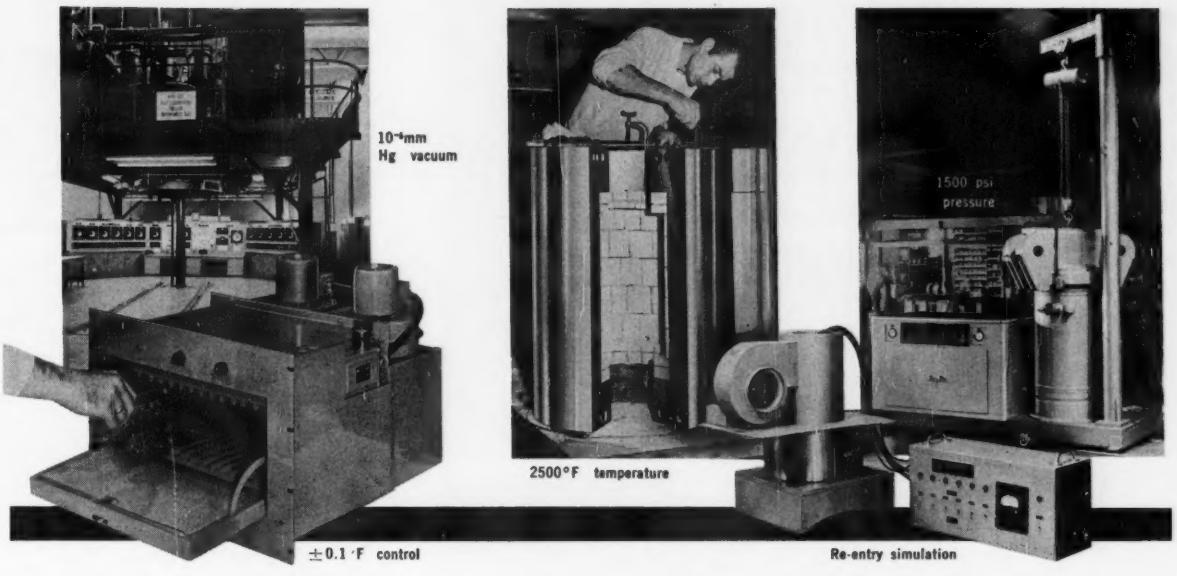

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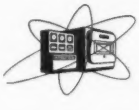

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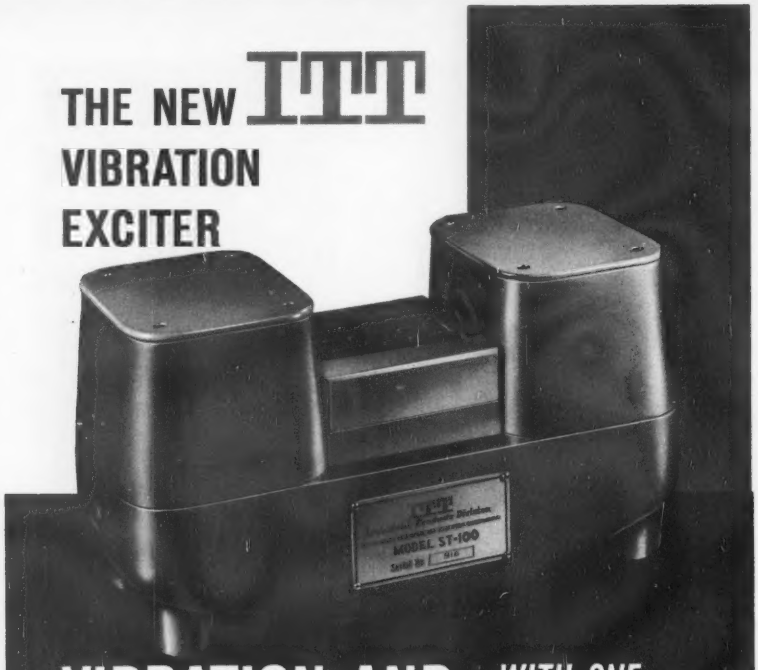

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IES NEWSLETTER

SAN DIEGO CHAPTER

A Dinner Meeting was held on November 14, of the San Diego Chapter. Mr. C.C. Campbell, Design Specialist, of Convair Astronautics was guest speaker. His topic was "A Combined Environmental Testing Program for Increasing Atlas Missle Reliability".

GREATER CHICAGO CHAPTER

The Greater Chicago Chapter has recently announced the naming of Mr. Robert O. Scholle as new Publicity Chairman. Mr. Scholle is with Inland Testing Laboratories ig Morton Grove, Ill.

BOSTON AREA CHAPTER

The regular meeting of the Boston Area Chapter of the Institute of Environmental Sciences on August 16, 1960 was held at Avco Research & Advanced Development Corp., Wilmington, Massachusetts.

Mr. Leonard A. Seder, nationally known quality control consultant, spoke to the group on the topic, "Statistics in the Testing Laboratory." Mr. Seder's discussion of a vital subject was both interesting and informative.

New officers were named at an important meeting of the Executive Committee following the Chapter meeting. Mr. Joe Gaudet of Sanders Associates assumed the duties of President in accordance with the Chapter By-Laws on the resignation of Gerhard Doering who is leaving to accept a position in the Philadelphia area. Mr. Ralph Marcus, Raytheon Company, Sudbury, Massachusetts, was appointed Vice President to fill the office vacated by Mr. Gaudet. Mr. Marcus will also continue his duties as Chairman of the Membership Committee.

The following appointments were also made by the executive committee to fill unexpired terms:

Elmo Pacini, Raytheon Co., Sudbury, Secretary
Dorman Priest, Ling-Calidyne, National Director
David Hemingway, Richard D. Brew and Company, Inc. Chairman, Publicity Committee

GREATER DENVER AREA

Mr. Jerry Bakalish, Member I.E.S. and Past President of the Los Angeles Chapter is now located in the greater Denver area and is actively working to form a Chapter in that area. Any interested in more information concerning A Greater Denver Area Chapter of the I.E.S., Please contact Mr. Jerry Bakalish, The Martin Company, P.O. Box 179, Denver 1, Colorado.

LOS ANGELES CHAPTER

The regular meeting of the Los Angeles Chapter was held on December 5, 1960. Guest speaker was Mr. W.K. Stewart, Project Engineer, Dynapak/Convair Division of General Dynamics Corp., Pomona. His topic of discussion was the recent developments and applications HY-GE Shock Test Machine.

(Continued from page 20)

θ angle around leading edge (in plane normal to leading edge) from the $\alpha = 0$ stagnation point to the $\alpha \sim 0$ stagnation point.
λ actual (geometric) sweep-back angle
λ_{eff} effective sweep-back angle (corrected for angle of attack)
μ viscosity of air (dynamic)
ρ air density
σ Stefan-Boltzmann radiation constant
ϕ angle around blunt nose or leading edge, measured from stagnation point

SUBSCRIPTS

o value at earth's surface
t stagnation condition
w wall value
∞ free stream value

REFERENCES

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2. Lees, L., "Laminar Heat) Transfer Over Blunt-Nosed Bodies at High Supersonic Speeds," Jet Propulsion, p 263, April 1956.

3. Multhopp, Hans, (unpublished data), Technical Director, Advanced Programs Group, The Martin Company.

(Continued from page 22)

How Far to go in Additional Random Vibration Equipment by N.A. COOK; Air Arm Division Westinghouse Electric Corporation.

A survey was made of existing literature to determine the nature of the vibration environment on missiles and aircraft. Based on this survey, a practical approach to random vibration simulation in the laboratory is discussed.

Design Consideration for Gimbal Structures Under Vibratory Force by J. HOFFMAN; Kearfott Co., Inc. Division, General Precision Equipment Corporation.

The increased vibration of high energy flight has caused drastic changes in the basic design of gimballed mounts. The techniques used in attacking problems of controlling natural frequency, resonance gain, and anisoelastic torques are given.

Incorporation of Cooling Air Into the Combined Environment Required for Simulation of an Aircraft Flight Profile by A. ARPIARIAN, R.G. BARAN & J.C. WARD; General Precision Laboratory, Inc.

A discussion of techniques used to supply cooling air to electronic equipment under varying environmental conditions to simulate high speed aircraft will be presented.

A Comprehensive Method for Evaluating Performance of a Missile Radar Under Environmental Stress by S.G. HIBBEN, HUGH C. JONES & J.T. TURNER: Air Arm Division, Westinghouse Electric Corp. & HAROLD C. JONES; University of Maryland, Electrical Engineering Dept.

In the test program described, a method for making a comprehensive performance evaluation of a missile radar undergoing environmental stress is given. Also included is a plan to establish a high degree of confidence that the required reliability was maintained when in the environment.

Self-Verifying Automatic Digital Ground Support Equipment by S. LISS; Kearfott Division, General Precision, Inc., Little Falls, New Jersey.

This paper describes new equipment which may be used for testing components in environmental test chambers and supplies a unique solution to testing problems in that it is self verifying. The equipment makes possible the elimination of human factors in the interpretation of tests.

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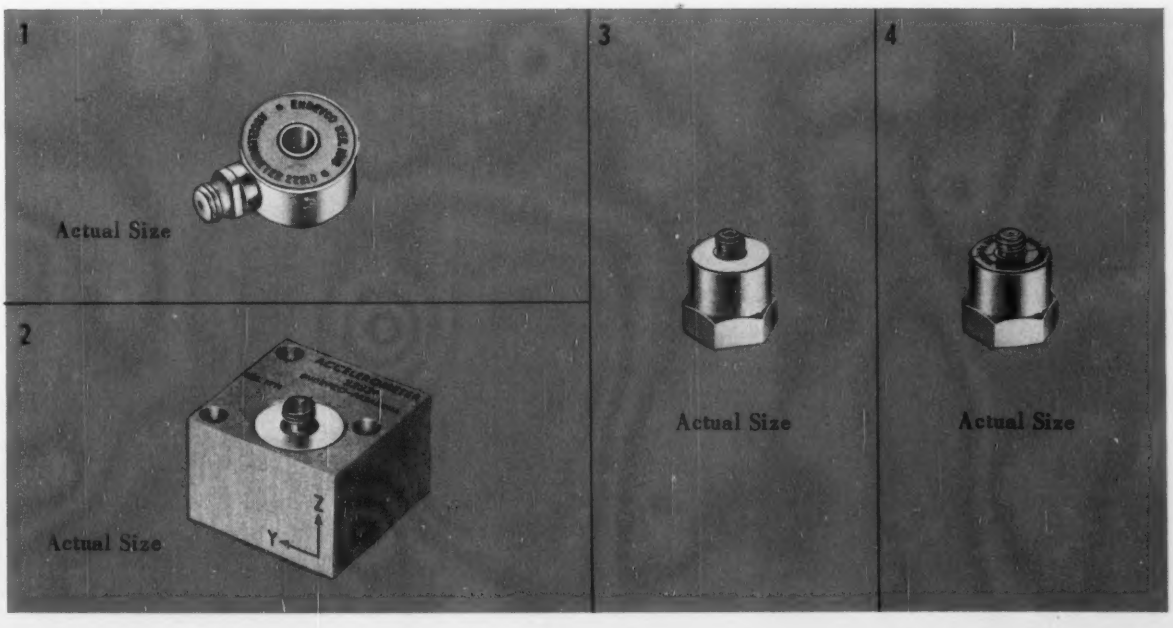

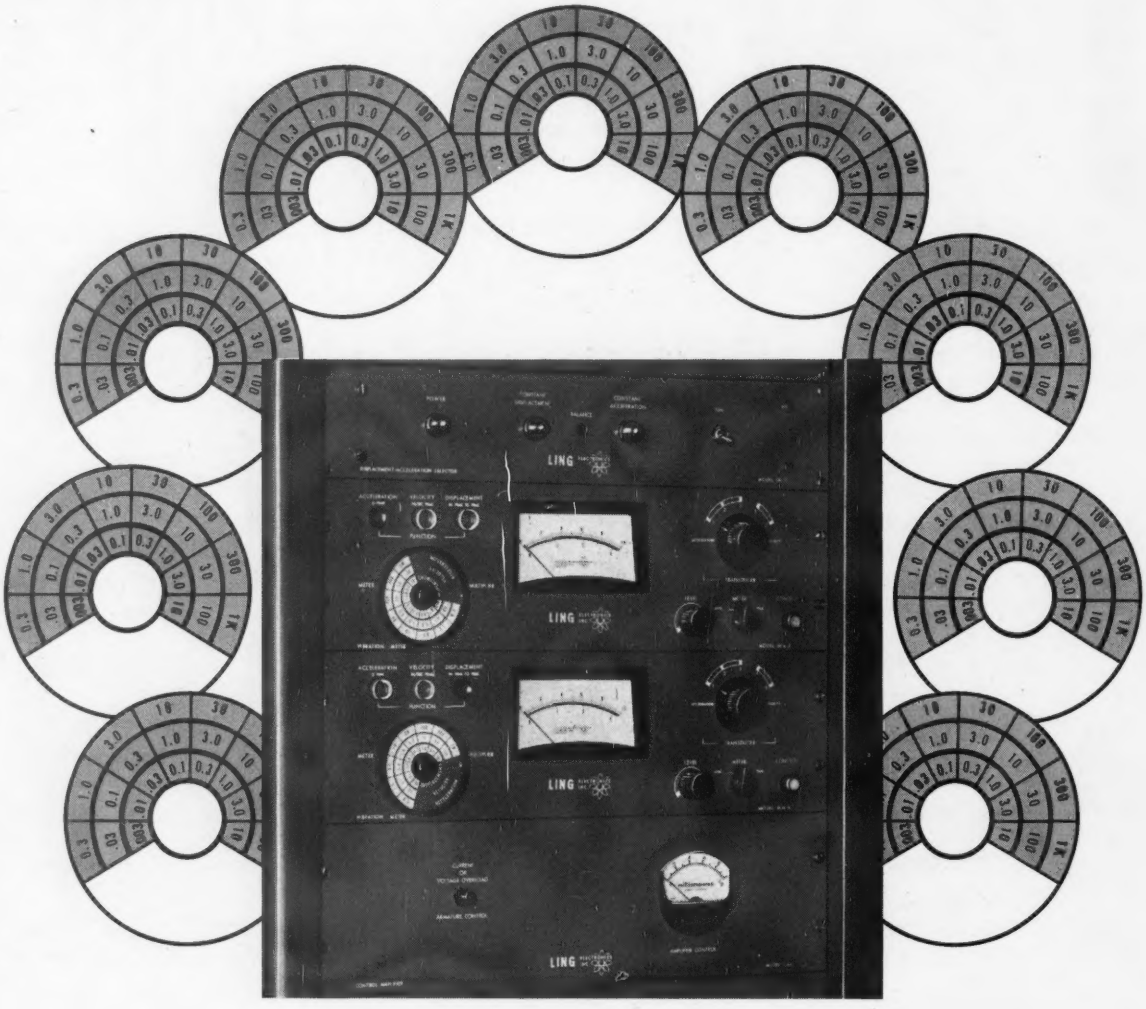

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